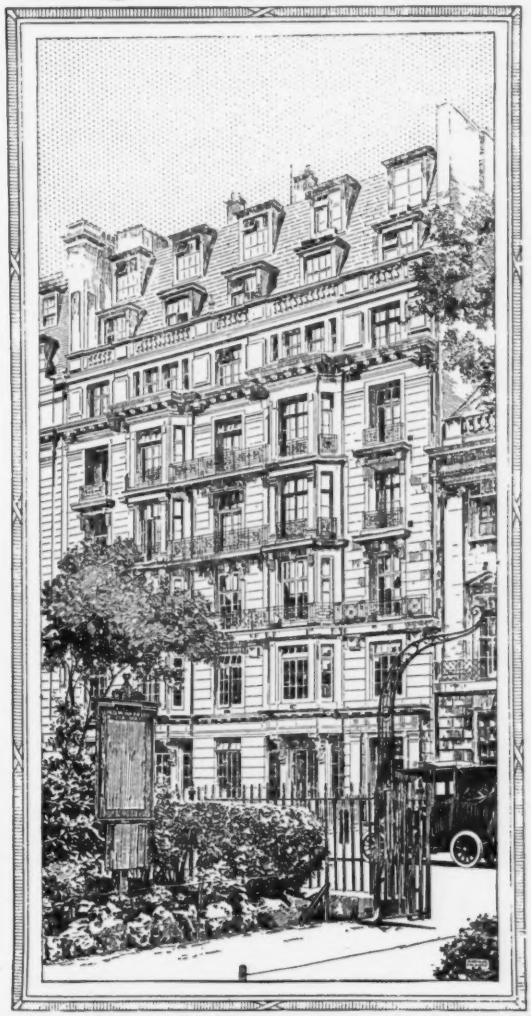
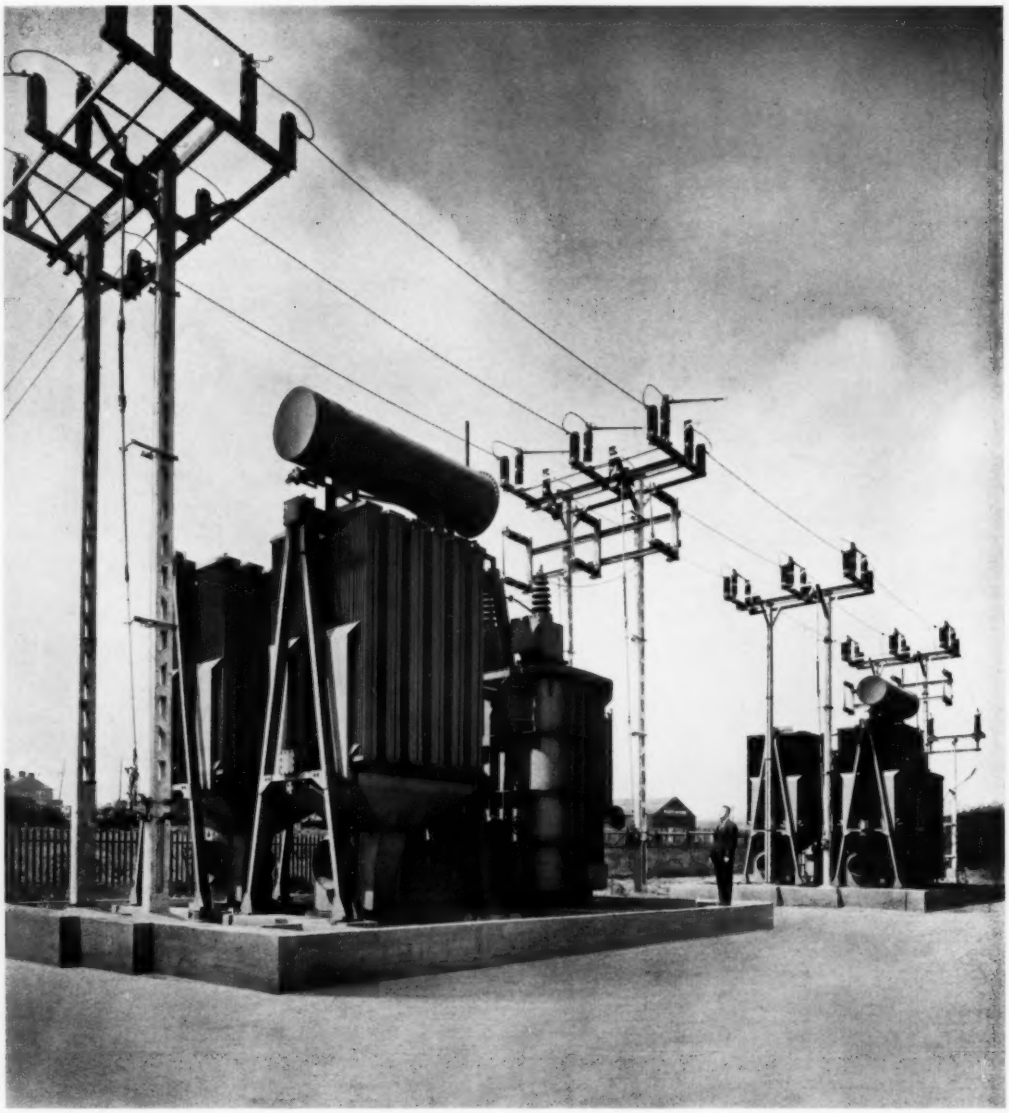
The ENGLISH ELECTRIC JOURNAL



Queen's House from Lincoln's Inn Fields.

All rights of republication, including translation of articles, are reserved.



40,000 kVA. 66 kV./33 kV. Transformer installed at the Birchfield Lane, Oldbury, Substation, of the Shropshire, Worcestershire & Staffordshire Electric Power Company.

BABCOCK *Class One* FUSION WELDING

L.N.E.R. Locomotives Nos. 1509 and 1535 were turned into traffic early in 1938, in the North Eastern Area. Known as J.39 Class Locomotives, they are designed for fast goods and special passenger service and are of particular interest as the boiler barrels are constructed by the Babcock Class One Fusion Welding Process, and as such represent one of the first orders for these welded pressure vessels for use in England. The barrels are 5' 6" outside diameter × 9' 8" long and designed for a pressure of 180 lbs. per square inch. Three such barrels were constructed. The illustrations show the welded boiler barrel, the complete boiler being lowered into the frame in the erecting shop, and the finished locomotive.

We are exhibiting at the Empire Exhibition, Glasgow, May — October 1938.

BABCOCK & WILCOX LTD.

BABCOCK HOUSE, 34 FARRINGDON STREET, LONDON, E.C.4.

OUTSTANDING EXAMPLES
OF FITNESS TO PURPOSE

'ARCLIGHT'

DRAFTING EQUIPMENT

SEND FOR CATALOGUE E./X.

ILLUSTRATED AND DESCRIBED IN THE COMPLETE CATALOGUE OF
"ARCLIGHT DRAFTING EQUIPMENT"

Particulars of separate units enabling Draughtsmen to build almost any Specification to individual requirements.

E. N. MASON & SONS LIMITED
ARCLIGHT WORKS COLCHESTER
Telephone: COL 2266 (2 Lines)
LONDON: 8/9 IVY LANE, E.C.4 - Tel.: CITY 5676 (3 Lines)

IOCO *Insulation*

FOR QUALITY AND RELIABILITY

"LINAPEX" VARNISHED CLOTHS AND TAPES
Straight Cut, Bias Cut, Seamless and stitched

"LINAPEX" VARNISHED SILKS AND TAPES

"LINAPEX" OILED PAPERS
For Telephone Insulation etc.

"FORMAPEX" MIOCARTA SHEETS

Grade I	B.S.S.	547.	P.F.
Grade II	,,	316.	P.O.
Punching Quality		-	P.Q.

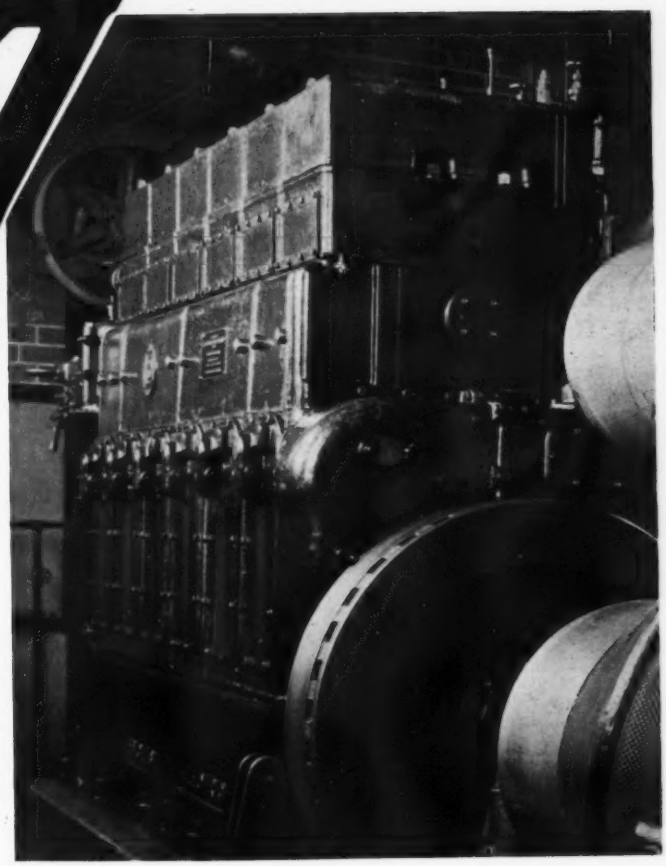
"FORMAPEX" MIOCARTA TUBES
Wrapped - P.G. Moulded - P.P.

"FORMAPEX" VARNISHED PAPERS
B. Quality, Coated for wrapped tubes.
L. Quality, Impregnated for moulded tubes etc.

Write for our booklets on Insulation, post free

THE IOCO RUBBER & WATERPROOFING CO., LTD.
NETHERTON WORKS - ANNIESLAND - GLASGOW

GERM OILS



300 B.H.P. at 300 R.P.M.

A 6-cyl. ENGLISH ELECTRIC Vertical Diesel Engine running on "GERM" oil—the only oil made on the **Wells-Southcombe process for increasing "oiliness."**

"GERM" Oils combine maximum oiliness with high stability and are in daily use in "ENGLISH ELECTRIC" and other Diesels in over 50 countries.

There are grades of "GERM" oil for every type of engine.

GERM LUBRICANTS LTD.

Telegrams: MAXOILI, LONDON. **City Gate House, London, E.C.2. Works: Salford, Lancs.** Telegrams: MAXOILI, MANCHESTER

THE spring properties of phosphor bronze strip account for many of its uses in the electrical industry. It is used for the manufacture of a wide variety of spring contacts such as knife switch contacts, wiping contact arms, plug sockets, laminated brush backings, etc., etc.

On the other hand it may be used in preference to copper for pressings in which rigidity is needed, since its greater strength permits a thinner gauge of metal to be used and so affords a reduction in weight.

Boltons can supply phosphor bronze strip and wire in exactly the right grade and temper to suit the requirements of any particular part or any particular manufacturing process.

ESTABLISHED 1783

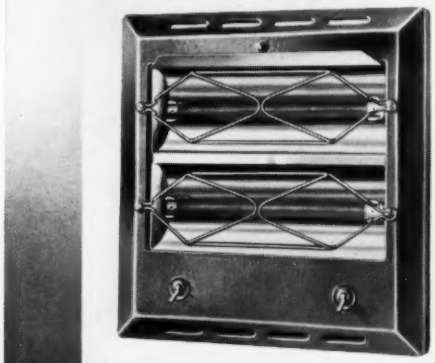
Thomas BOLTON & Sons Ltd

Head Office: MERSEY COPPER WORKS, WIDNES

London Office: 168 REGENT ST. W.1

'ENGLISH ELECTRIC'

INSET FIRES



The fire illustrated has reflector-type elements fitted in close grain cast-iron front frame, vitreous enamelled. Each element is controlled by a separate double-pole switch.

1kw., Cat. No. H.H.146 Price **30/-**
2kw., Cat. No. H.H.147 Price **42/6**

These fires can be supplied with a sheet-metal surround, which enables the fire to be fixed without recessing the wall.

Price of surround in each case **7/6** extra.

In thousands of homes "English Electric" fires are giving trouble-free service and these reflector-type inset fires with their neat appearance, modern design and remarkably low prices have created a further wide demand.—Stock and recommend "English Electric" Fires.

When you visit the Empire Exhibition, Scotland, don't fail to see our exhibits Stand No. E237, Palace of Engineering.

THE ENGLISH ELECTRIC Co. LTD

DOMESTIC · · APPLIANCE · · WORKS

PRESTON.

Supreme from 1891

STERLING INSULATING VARNISHES have been pre-eminent throughout the electrical trade ever since they were first placed on the market.

STERLING INSULATING VARNISHES have consistently maintained a high degree of quality enabling them to withstand the test of time, and consequently they have been approved and are in constant use by the largest electrical manufacturers and repairers.

THE STERLING VARNISH COMPANY, LIMITED,
Fraser Road, Trafford Park,
Manchester 17.

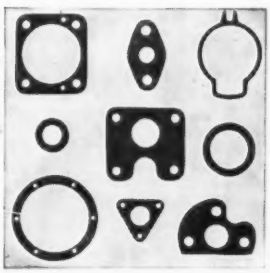
Telephone: Trafford Park 2231.
Telegrams: "Dielectric" Manchester.

SPECIFY **STERLING** AND BE SAFE

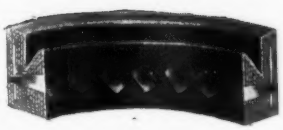
PACKINGS & JOINTINGS

FOR ALL PURPOSES AND PRESSURES

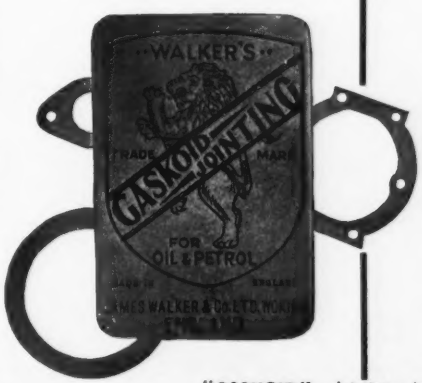
WALKER'S LION PACKING



"GRAFITOIL" JOINTING
For very Hot Oil Joints. This Jointing possesses great tensile strength. Sample for testing gladly supplied. Obtainable in sheet and cut joint form.



"LION" AUTOMATIC TYPE
For Accumulators, Hydraulic Lifts, Cranes, Presses, etc. Will stand the highest pressure with the minimum of friction.



"GASKOID" Jointing is permanently Oil and Petrol resisting. The material is tough yet supple and is used extensively on very important jobs. Write for Free Trial sample

WRITE FOR CATALOGUE H.6.

EMPIRE EXHIBITION, GLASGOW—OUR STAND No. is E. 93, PALACE OF ENGINEERING.

JAMES WALKER & CO., LTD.
"LION" WORKS · WOKING · SURREY
PHONE. WOKING 2255 (4 lines). — GRAMS. LIONCELLE

ASQUITH

REDUCE DRILLING COSTS
and
INCREASE EFFICIENCY

by insisting that your machines are equipped with Asquith "BETTER-SERVICE" SOCKETS.

"BETTER-SERVICE" SOCKETS are case-hardened and ground to accurate limits both internally and externally and retain their initial accuracy over very long periods of useful service.

Progressive firms standardise on "BETTER-SERVICE" SOCKETS.

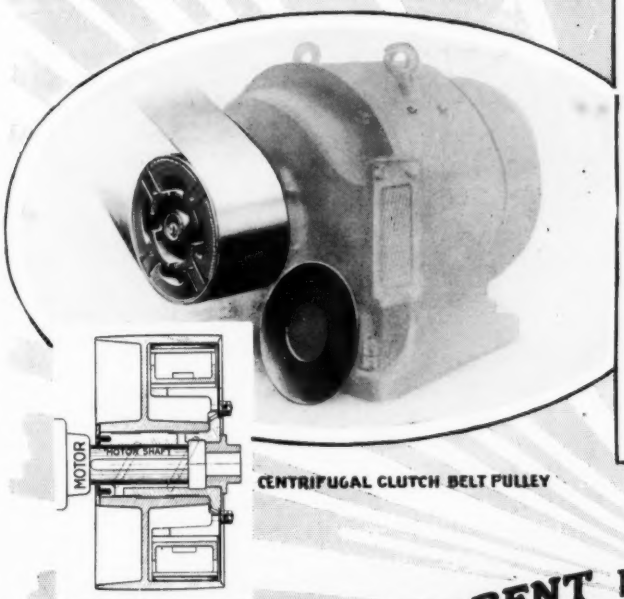
MADE FOR
ACCURACY AND LONG LIFE

NOTE REDUCED PRICES

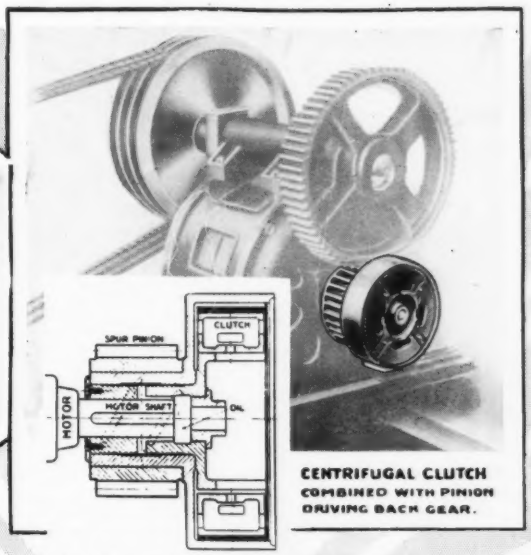
Inside Taper (Morse Standard)	Outside Taper	Price each s.	d.
No. 1	To suit No. 2 Morse	5	0
,, 1	,, 3 ,,	6	3
,, 1	,, 4 ,,	7	6
,, 1	,, 5 ,,	12	6
No. 2	,, 3 ,,	6	3
,, 2	,, 4 ,,	7	6
,, 2	,, 5 ,,	12	6
No. 3	,, 4 ,,	7	6
,, 3	,, 5 ,,	12	6
No. 4	,, 5 ,,	12	6

Special terms for Quantity Orders

WILLIAM ASQUITH, LIMITED, WELL ROYD WORKS,
Telephone: 61258/9, 61250 **HALIFAX, England** *Telegrams:* Drill, Halifax



CENTRIFUGAL CLUTCH BELT PULLEY



CENTRIFUGAL CLUTCH COMBINED WITH PINION DRIVING BACK GEAR.

The BROADBENT Patent CENTRIFUGAL CLUTCH

ENSURES EASY STARTING OF MOTOR AGAINST FULL LOAD WITH MINIMUM CURRENT

For starting up all classes of machines with large inertia to overcome a Broadbent Clutch is often absolutely necessary

Let us send a copy of our Catalogue

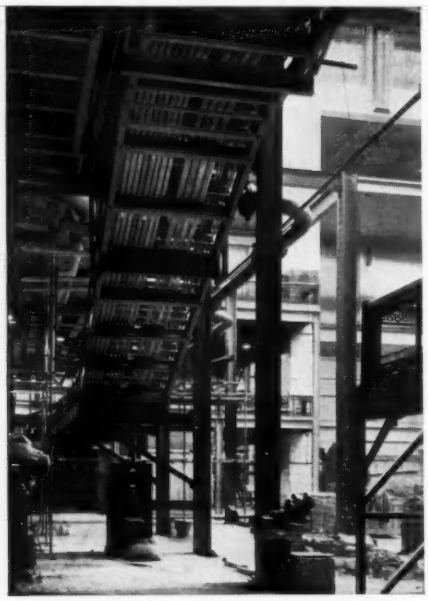
THOMAS BROADBENT & SONS LTD.

Telephone:
1581 (4 lines)
HUDDERSFIELD

HUDDERSFIELD

SIEMENS

Manufacturers of



Underneath view of cables crossing turbine house at Battersea Generating Station.

ALL CLASSES OF

ELECTRIC CABLES

AND

CABLE LAYING

&

JOINTING MATERIALS

The illustration shows power cables installed by us in a position less familiar than that seen by the roadside. It is an example of our practical experience which is at your service.

PRIVATE TELEPHONE SYSTEMS

for Offices, Factories, Public Institutions, etc.

CELLS & BATTERIES

OVERHEAD LINE MATERIAL

ELECTRIC LAMPS

etc.

Siemens "Neophone" as standardised by the British Post Office.

Over 80 years' electrical experience

SIEMENS BROTHERS & CO., LTD.,

WOOLWICH, LONDON, S.E.18.

Tel.: Woolwich 2020.

The English Electric Journal

Vol. IX. No. 2 JULY, 1938. One Shilling.

CONTENTS.

	PAGE
WETNESS IN STEAM TURBINES -	33
SCIENTIFIC DEVELOPMENTS IN TRANSFORMER CONSTRUCTION	41
ELECTRIC FUSES: SOME OBSERVATIONS ON B.S.S. 88/1937, ETC. - - - - - -	55

All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD.

EDITORIAL.

With the modern tendency towards high steam pressures and temperatures, the subject of the wetness of the steam in the low-pressure stages of steam turbines is becoming increasingly more important and in the first article, entitled " Wetness in Steam Turbines," by Mr. L. C. Hookins, the subject is dealt with from both the theoretical and practical standpoints. The article illustrates the effect of increase of initial steam pressure on the wetness at the exhaust of the turbine, and curves are given indicating the comparative wetness at the exhaust, with different sets of initial steam pressure and temperature conditions and with different vacua.

Means of improving the wetness condition in the low-pressure stages of steam turbines are also discussed, particularly as regards the methods which have been adopted for extracting as much water as possible from the steam in its passage

through the turbine, and in reducing to a minimum, by the fitting of specially hardened steel shielding on the last L.P. blades, the erosion of the blading caused by the moisture in the steam which it is impossible to extract. Typical photographs are included showing the effect of the water-cutting on low-pressure blading caused by wetness in the steam, firstly with normal stainless blading without special protective shields, and secondly, similar blading fitted with protective shielding on the last L.P. blades after approximately the same period in service.

In brief, the article summarises the investigation, research and experimental work which has been carried out in the Mechanical Testing Laboratories of the Company at the Rugby Works during recent years and which work is still proceeding with a view to reducing still further the effect of moisture in the low-pressure stages of steam turbines, and increasing both the efficiency and life of the blading.

" Scientific Developments in Transformer Construction " is the title of the next article, which this is the fourth and concluding one that Mr. R. M. Charley has contributed under this heading. Previous articles dealt with transformers for power transmission in bulk and transformers for general distribution purposes. The article under review gives a very interesting outline of transformers for special applications and shows the wide range of alternating current work for which transformers are required. The Author deals with transformers for rectifiers, arc-furnaces, A.C. arc-welding, low-voltage transformers for " safety lighting," and reference is also made to earthing transformers and interconnected-star balancers.

In the last article Mr. A. M. Pooley continues his remarks on " Electric Fuses," which appeared in our last issue.

Details of laboratory and service tests in substantiation of our claims for non-deterioration are given, and the results of many discrimination tests reviewed, including comparative tests of high speed, high rupturing capacity fuses and open copper wire fuses.

The new " S.S." 25-ampere, 250-volt, B.S.S. category A.C.3 and D.C.3 fuse and fitting is illustrated.

Wetness in Steam Turbines.

By L. C. HOOKINS, A.M.I.Mech.E., Steam Turbine Department.

Steam, although an invaluable medium for the conversion of heat energy into work, has the characteristic that when it is expanded under conditions where its heat is given up and the expansion is carried beyond the saturated zone, water forms in the steam. Hence, when steam is expanded to a vacuum, in, for example, a steam turbine, the formation of water in the low-pressure stages is a natural consequence, which results in wear of the blading, and at the same time tends to reduce the efficiency of the turbine.

The presence of this water has, therefore, to be carefully considered in steam turbine design and operation, and it is proposed in this article to examine the general nature of the problems involved, and to consider the measures which can be taken to combat as far as possible the harmful effects of the water formed.

It will be of service to illustrate, by means of the Mollier Diagram, the expansion of steam in a turbine exhausting to a vacuum, and show how the operating steam and vacuum conditions, together with the various losses in the turbine, all affect water formation.

Fig. 1 shows a portion of a simplified Mollier Diagram or " Heat-entropy " chart, an invaluable means of readily determining the behaviour of steam during expansion and its properties under various conditions ; in this diagram the abscissæ represent entropy and the ordinates total heat. In this simplified diagram only lines of constant pressure (including vacuum lines), temperature, and wetness, have been shown.

A vertical line, such as AB, drawn from any initial steam condition to a lower pressure, shows the intermediate and final states of the steam when expanding adiabatically, i.e., with constant entropy, all the heat given up being converted into useful work. This line, therefore, represents expansion accomplished at 100 per cent. efficiency and shows in principle the effect of initial conditions and final pressure on the moisture content, when the expansion enters the region below the dry saturated condition. Consider such an expansion between any two constant pressures ; it will be seen from the lines AB and CD that the higher the initial temperature the less will be the amount of moisture present at the lower pressure. This is one of the reasons for the improvement in economy resulting from the adoption of higher steam temperatures. It will also be apparent that the lower the final pressure the greater will be the wetness when expanding from any given set of initial conditions. A comparison between CD and CE shows this effect. The moisture content arising from this latter circumstance, however, has to be accepted with as good grace as may be, for, from considerations of operating economy, a condensing turbine must be run with as low an exhaust pressure as possible, in order to extract the maximum amount of heat from the steam. This back pressure, more often expressed in terms of vacuum, is governed almost entirely by the quantity and, more particularly, the temperature of the cooling water available for the condenser.

Apart from the operating steam and vacuum conditions another factor governing the quantity of water formed is the efficiency of the turbine ; the greater the efficiency the greater the amount of water. Reference to Fig. 1 will establish this fact. As stated, a line such as CE represents an expansion of 100 per cent. efficiency, and for any other value the final state of the steam is found by multiplying the adiabatic heat drop CE by the internal efficiency of the turbine, marking the

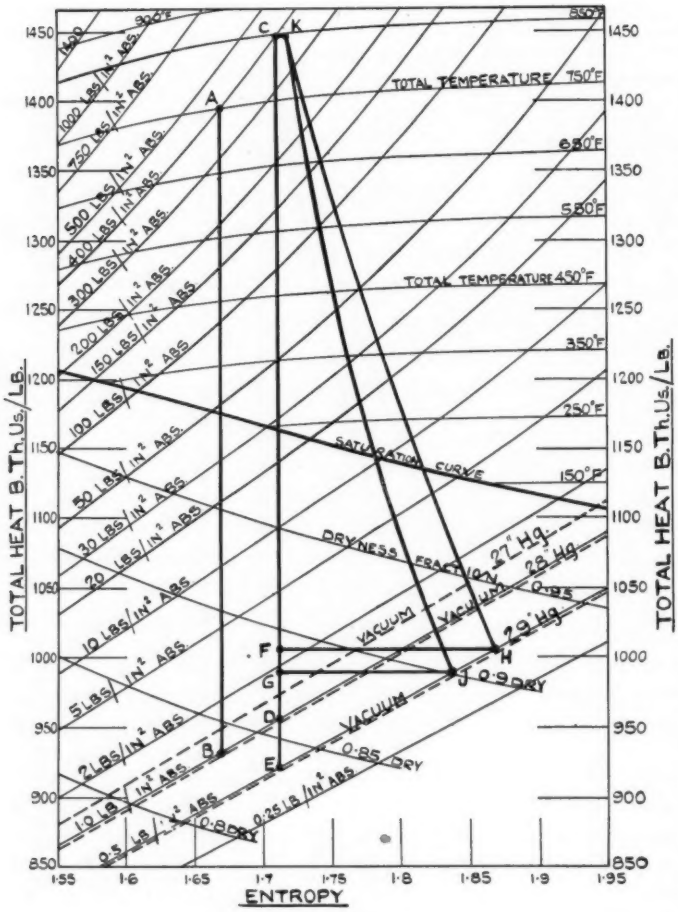


Fig. 1.—Mollier Diagram for Steam.

value obtained along the adiabatic from point C and drawing a horizontal line from the point thus obtained, e.g., F or G, to cut the back-pressure, or vacuum, line at H or J. These two points show the state of the steam at the end of the expansion point H representing an internal efficiency of 84 per cent. and point J 87 per cent., and it will be seen that the higher the efficiency the wetter will be the steam for any given initial steam conditions and exhausting to the same vacuum. The two sets of curves given in Fig. 2 show the amount of moisture present at the end of expansions effected at various internal efficiencies and for varying initial pressures and temperatures. One set is for a final vacuum of 28 in. Hg. and the other 29 in.

It would perhaps be of interest also to give an explanation here as to the losses involved in arriving at the internal efficiency, and which losses show on the heat chart.

Briefly, any loss which affects the quality of the steam influences the position on the chart of the expansion line. For example, interstage leakage improves the quality in succeeding stages, as the leakage steam does no work in the stage concerned, therefore loses no heat, and consequently renders the steam at the next stage slightly more superheated (or drier if in the wet region) than would otherwise be the case. Steam friction and windage are other losses having a similar effect.

On the other hand, mechanical losses such as bearing losses, power taken to drive oil pumps, governors, etc., have no influence on the condition of the steam, but merely affect the overall efficiency and hence the amount of steam required to be put through the turbine.

Steam leaking from main shaft glands, if utilised in gland heaters, does not affect the quality of the steam in the turbine, but if reintroduced into the turbine at a lower point tends to improve the quality there.

Consider the expansion line CJ (Fig. 1) where the initial pressure and temperature of the steam at the turbine stop valve are represented by point C; there is first an expansion at constant total heat to the point K, where the pressure is some 5 per cent. less than at the stop valve. This drop occurs across the governing valve and has to be allowed for governing purposes. No

work is done by the steam in this expansion, which, therefore, is carried out at constant total heat and has the effect of improving slightly the quality of the steam throughout the remainder of the turbine. (This is not, however, a nett gain. The improvement in quality resulting from any of the internal losses mentioned is only a partial recovery of those losses.)

At point K the steam enters the blading and the expansion line KJ is built up stage by stage by calculating the internal efficiency and marking off the useful heat drop down the adiabatic line for each stage in a similar manner to that adopted for finding the final state point J for the whole machine.

When desiring to arrive at the state of the steam as it leaves the last row of blading, the leaving loss has also to be calculated and allowed for on the heat chart. The steam must, of course, have some exit velocity from the blading, although it is the aim of the designer to keep it as low as possible, because the energy locked up in the weight of steam moving at this velocity is a dead loss. It is usually of the order of from about 1¼ per cent. to 3 per cent. on a modern high-efficiency turbine.

The internal efficiency then is arrived at by increasing the overall turbine efficiency (which is readily calculated, knowing the available heat drop and the alternator efficiency) by the percentage of the mechanical and leaving losses, together with the main shaft gland losses if the gland leakage is taken to heaters and not led back into the turbine. The curves (Fig. 2) illustrate clearly the influence on final wetness of initial pressure and temperature, and also of internal efficiency. They show the increase in moisture content accompanying improvement in

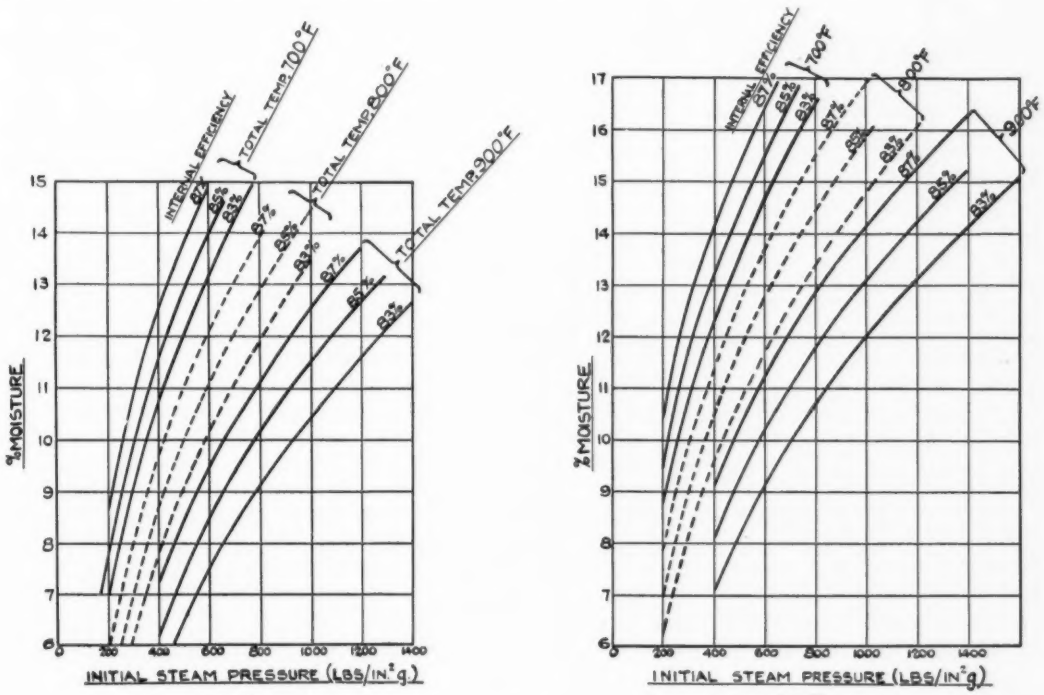


Fig. 2.
Curves showing percentage moisture at discharge of last blade with various initial steam conditions and internal efficiencies.

efficiency, and the decrease by raising initial temperatures. A comparison of the curves under the two vacua shown establishes the effect of final pressure.

The internal efficiencies shown would not be realised under some of the more extreme steam conditions and the curves have been prolonged beyond the usual design limits, merely to show how the various factors affect the moisture content. Under modern steam conditions the maximum moisture content is generally between 10 per cent. and 13 per cent.

There is one method of dealing with the water problem which has not yet been referred to, as it is not very commonly employed. This method consists of extracting the whole of the partially expanded steam from an intermediate stage of the turbine, reheating, and returning it to the turbine in a superheated condition. The reheating can be carried out either by means of live steam, or by boiler gases in heaters incorporated in the boilers, or again, in separately fired heaters.

In the two latter cases the steam can be reheated up to, or near, the original total temperature. In cases where the reheating is effected by means of live steam, the temperature attained is dictated by the pressure of the live steam, being the dry saturated temperature of the latter. The wetness at the exhaust may be considerably reduced by reheating, but although this system has been adopted in some cases both at home and abroad, it is by no means common. The chief objections are on account of expense and complication. The reheating has necessarily to be carried out at a fairly low pressure, involving large diameter pipe lines to and from the heater. These are particularly objectionable in cases where the latter is situated some distance away from the turbine, as, for example, in the boiler house, which would be the situation of high-temperature reheaters. Special and elaborate provision has to be made in these cases, firstly, to regulate automatically the temperature of the gases to avoid the risk of burning out heater tubes at the lighter loads when a reduced quantity of steam is being dealt with, and, secondly, to by-pass automatically the steam contained in the piping and heater if the load on the turbine is suddenly thrown off, as the amount of steam in these would, in many cases, be sufficient to overspeed the turbine under such circumstances.

Reheating by live steam is relatively free from these disabilities, but the reheat temperature is limited and therefore the reduction of wetness not so pronounced.

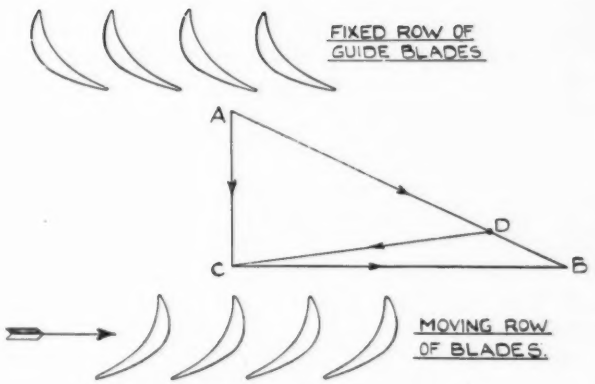
For these reasons, reheating is not a common feature on turbine plant, and the general problem of wetness may be considered from the point of view of turbines in which the steam is expanded uninterruptedly from the initial temperature to a vacuum. This being so, it is evident from the foregoing consideration of the causes, that from the point of view of dealing with the evil at the root, all that can usually be done to prevent the formation of water is to adopt as high a steam temperature as possible. At the same time it will be appreciated that it is not reasonable to choose steam conditions solely from the aspect of blade wear and as considerable economies are realised by the use of high pressures, the natural trend is to employ the highest temperature permitted by the materials available for use in boiler and turbine construction, and a pressure which will give economical operation with not too great a moisture content in the low-pressure stages of the turbines. The presence of a certain amount of water in the low-pressure stages of a turbine has to be faced, therefore, and the problem remains as to how its effects can be mitigated.

The water appears in the steam in the form of a fine mist, and in that state does little harm to the blading as far as erosion is concerned, as it is carried along at steam speed and thus enters the blading without shock and at the correct angles.

As the steam is turned during its passage through a row of blades, however, some of the water is deposited on the blade surfaces and is blown towards the discharge edges, where it collects until sufficient bulk has accumulated to be torn off by the steam in the form of small drops. Starting from rest, these drops require much more space than that which exists between rows of blades in which to acquire the velocity of the steam. The space referred to being shown by AB in Fig. 5. As a consequence, the comparatively slow moving drops of water approach

the moving blades at an angle quite at variance with the steam, and hence strike the edges of the moving blades instead of entering with the steam without shock.

Fig. 3, which shows a typical velocity diagram, illustrates this point. AB represents, in magnitude and direction, the absolute velocity of the steam issuing from a row of fixed guide blades, CB the velocity of the moving row of blades; therefore AC gives the velocity and direction of the entering steam relative to the moving blades. In the example shown, where reaction type blading is portrayed, the steam enters at right angles to the row of moving blades and the inlet angles of the blades are designed for entry in that direction. In the short distance between fixed and moving rows, however, the water drops blown off the discharge edges of the fixed blading, by the time they reach the moving blades, will only have a velocity approximating to, say, the distance DB and their velocity relative to the blades in magnitude and direction is therefore DC. This is almost equal to blade speed, so that the greater the latter the greater is the impact. Here lies the cause of the increased blade wear which has been observed, as blade diameters and hence blade speeds have been increased.



AB = Absolute Steam Velocity.
DB = Absolute Water Drop Velocity.
CB = Blade Velocity.
AC = Steam Velocity Relative to Moving Blade.
DC = Water Drop Velocity Relative to Moving Blade.

Fig. 3.—Typical Velocity Diagram.

Considering now the effect of vacuum. This has a double influence. Firstly, as already shown, the higher the vacuum the more the moisture content, and, secondly, the less dense is the steam. It will be obvious that for any one steam speed, the less the density of the steam the smaller will be the velocity which can be imparted to water drops in the space between two rows of blades. Hence, referring again to Fig. 3, the higher the vacuum the smaller the distance DB and therefore the greater the velocity of the water drops relative to the blades, which results in more violent impact.

A practical proof of the general truth of the velocity diagram shown is forthcoming from an inspection of eroded turbine blades, when the inlet edges will be seen to be cut off (as shown in Fig. (4A) at an angle which is indistinguishable from the direction of motion. In fact, it would appear that in most cases the direction of the drops relative to the blades lies even closer to the blade motion than is shown in Fig. 3. Additional proof of this is afforded by examination of blades which are shielded, a subject which will be referred to later in this article. It will be observed frequently that a particular shield has been attacked more than its follows, and if a straight edge is laid across the inlet edges of the group of blades in this vicinity it will be found in most cases that the blade concerned stands slightly proud. Quite a small difference in level—less than one-sixteenth of an inch—will suffice to account for a considerable difference in the roughening of the shields by water. Sometimes it is noticeable that the blade which stands proud completely protects the one following.

It will perhaps be remarked that only water drops torn off the discharge edges of the stationary blading on to rotating blading have been considered, and not the reverse case. The reason is that the bulk of the water which collects on rotating blades is thrown outwards along the blades by centrifugal force, and finally on to the turbine casing. In this case, as distinct from the direct impact on a moving blade, the water strikes a glancing blow on the casing and, as

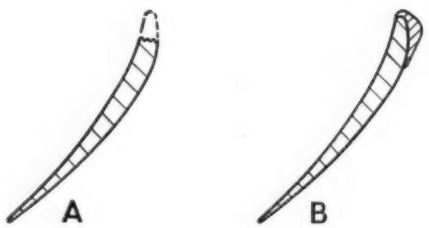


Fig. 4.

may be expected, the wear, although apparent, is not so severe. Due, then, to the centrifugal flow of water on moving blades, less is projected axially across to the next row of stationary blades and the latter are subject to less wear.

The mention of the throwing of water on to the casing leads conveniently to the consideration of the methods adopted of combating the harmful effects of water in a steam turbine. Obviously, there is no remedy for the moisture which is being carried by the steam in the form of a fine mist, but part of that which later on is deposited on the blades ultimately reaches the casing, and can be trapped by water catchers, of which one type is shown in Fig. 5. It consists of a circumferential groove in the casing, the leading edge being arranged slightly to overlap the discharge edge of a moving blade, thus receiving the maximum amount of the throw from that blade in addition to the water from preceding blade rows, which is travelling along the internal surface of the casing.

The groove leads into a separately mounted steel ring, which forms a lip preventing water which is caught in the top half falling back on to the blading. All water trapped flows in the ring to the lowest point of the bottom half. From here it is suitably disposed of in a low-pressure heater or led to the condenser. A certain amount of water is incidentally removed by steam which is bled from the turbine for the purpose of heating the condensate on its way to the boilers. This feed-heating by bled steam is a feature of modern turbine plant. Some water is carried out by steam tapped off for this purpose in the wet region, and where practical, lips are formed in the bled steam belt, preventing water falling back from the top half of the belt.

Referring again to the water which is trapped in water catchers, if it is led away by pipes to a point of lower pressure, it is obvious that if precautions are not taken steam will flow through with the water. The heat loss to the system will be slight if the drain in question is connected to a heater ; but if, as is more usual, the connection is to the condenser, then the loss may be considerable.

For this reason the drain piping from the water catcher is provided with a nozzle or orifice plate at its extremity in the condenser, and this is so dimensioned as to restrict the flow to water only. The arrangement is self-regulating, for as the load on the turbine varies the steam pressure at the water catcher changes almost in proportion to the amount of steam passing and

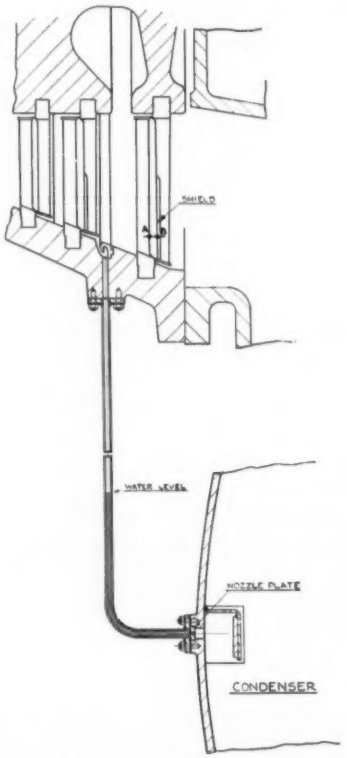


Fig. 5.—Typical Water Trap.

therefore the pressure head across the nozzle is increased or decreased with the amount of water present. The restriction must be situated at the end of the drain pipe, as an open-ended pipe to the condenser would not serve the same purpose ; the fall in pressure would take place in the pipe and some of the water would boil, generating steam, which would choke the flow owing to its much greater volume.

The function of the nozzle is to keep up the pressure on its inlet side, so preventing the ebullition of steam on that side. The lower pressure exists at the throat of the nozzle or at the discharge side of an orifice plate ; the steam is thus formed outside the drain system, where there is ample space for the consequent inflation in volume. It will be appreciated that it is difficult to arrive at an exact knowledge of the amount of water trapped by a catcher as the factors involved are numerous and complex, but considerable latitude in the design of the nozzle is permitted by the fall in the drain piping, which, containing water, adds a static head to the pressure on the inlet side. Although this static head is of the order of a few feet only, it is an addition to a very low steam pressure (usually well below atmospheric pressure where catchers are fitted) and therefore noticeably affects the total head across the discharge device.

Conflicting claims have been made as to the amount of water which can be removed from the wet region of a turbine by water catchers, but having regard to the fact that they can only trap water which collects and flows on the inner surface of the casing, it appears reasonable to expect the collection of some 20 per cent. or so of the water formed.

From the points so far mentioned, it will be appreciated that in spite of the precautions taken, some water will remain to erode moving blades, and the next consideration is of the methods adopted to reduce the erosion to a minimum.

Much research has been carried out on various materials, both on machines at site, and in the English Electric Company's Research Department* in apparatus which reproduces, by means of controllable water sprays and variable blade speeds, the water conditions existing in a turbine, but in a much more severe form so that the erosion which may be expected in practice to occur during months of operation can be obtained in experimental runs of reasonable time.

After many tests on different materials the conclusion reached was that more than just a hard surface was required. Chromium plating, for instance, provided a hard surface, but its effect on the retardation of blade wear was slight. The reason would appear to be that the impact between water drop and blade is so violent that the metal beneath the plating is deformed and breaks up, with the consequence that the plating flakes off. A hard surface, approximating to the hardness of tool steels, of considerable depth, is required. The blade itself cannot be made of material of sufficient hardness, as it would lack the necessary ductility to withstand fatigue set up by any vibration which might be present and, moreover, the material must not only be readily machinable, but also sufficiently ductile to allow the riveting over of the tangs which secure the shrouding where this is fitted. Again, in some cases the blades are subjected to brazing operations for the attachment of lacing wires, etc., and a very hard steel would not be suitable from this point of view as there would be a tendency to set up fine surface cracks during the heating and cooling of brazing.

It will be seen, however, by reference to the diagram in Fig. 3, that only the inlet edges of the blades are subject to erosion, the blades affording mutual protection elsewhere.

The most efficient protection evolved as the result of numerous experiments is provided by brazing a shield of tool steel (tungsten steel) on to the top portion of the inlet edge. The shield is of special shape, somewhat resembling in section a small turbine blade. Various sections are available, the choice being governed by the shape and angle of the blade to be shielded. Fig. 4(B) shows a typical section through a blade and shield. It will be noticed that the shield chosen presents a surface disposed at approximately 45 deg. to the approach angle of the water drops, thus sustaining a glancing, instead of a

* *See J. P. Chittenden, "Steam Turbine Research at Rugby Works," The English Electric Journal, June, 1937. (Vol. VIII. No. 6.)*

Fig. 6.—Unshielded last row of Blades.

Fig. 7.—Shielded last row of Blades.

direct, blow. A photograph of a typical shielded blade has appeared in a recent issue of this Journal*. This shows only the upper portion shielded, which is normal practice, the reason being that the blade speed is at its maximum at the tip, becoming less as the root is approached, and hence on the lower half of the blade the impact with water drops is less severe. Also, as noted previously, due to centrifugal action, the water drops are fewer in number towards the root.

Proof of the efficacy of the shielding is afforded by the two photographs shown in Figs. 6 and 7. Fig. 6 shows the erosion, due to water after about three years' operation, on the inlet edges of the last row of blading of a large high-efficiency turbine built by the English Electric Company some years ago. Fig. 7 shows the same stage after reblading with shielded blades, and after a similar period of use the operating conditions remained unaltered during the two periods.

This brief study of water in steam turbines will explain why the problem has only appeared in an acute form in comparatively recent years. In these years advances have been made in the direction of increased blade speeds, much improved efficiencies, and higher vacua. All these factors tend to increase the moisture content, and at the same time the higher temperatures which have been employed have been accompanied by higher pressures. The general effect, therefore, has been in the direction of accentuating the problem of blade wear by erosion, which is another instance of the common experience of additional complications following in the train of advances in design and construction.

* *See F. J. Cowlin, "The 'English Electric' Optimum Blade for Steam Turbines of Large Outputs," The English Electric Journal, December, 1937. (Vol. VIII. No. 8)*

Scientific Developments in Transformer Construction.

By R. M. CHARLEY, M.C., B.Sc., Mem.I.E.E., M.A.I.E.E

[*The three previous articles under this title were published in the September, 1936 (Vol. VIII, No. 3), December, 1936 (Vol. VIII, No. 4), and September/October, 1937 (Vol. VIII, No. 7) issues of this Journal.*]

Transformers described in previous articles are representative of those used for power transmission in bulk, or distribution to the ultimate consumer who uses the power for the more usual services. There are many other purposes for which transformers are employed, ranging from large units to supply arc-furnaces to a midget used for welding dental plates. The principles and features previously described are applied to these special transformers, but the unusual nature of the service in many cases demands further detailed consideration by the designer.

In recent years the mercury-arc rectifier has been employed almost exclusively for the supply of D.C. for traction purposes, and such equipments, totalling an output of many hundreds of thousands of kW., are now in service. Sometimes the rectifier is described as the "commutator" for the transformer, or, more briefly, as a "mutator"; indeed, that is its sole function, but in order to produce the best possible wave shape on the D.C. side, and also on the A.C. side, and to use the windings to the greatest economy, very special connections are used. Fig. 1 illustrates the core and windings of a rectifier transformer suitable for a D.C. output of 2,500 kW. at 3,300 volts D.C., the supply being 35,000 volts 3-phase. This equipment, supplied to the Polish State Railways, is described in the September/October, 1937 (Vol. VIII, No. 7) issue of this Journal. The rectifier is provided with six anodes and the secondary windings of the transformer are arranged in a six-phase fork connection, the primary side being star-connected. For rectifier transformers the sandwich arrangement of the H.V. and L.V. windings is sometimes used, but in the case under review the service conditions were such that the concentric arrangement of windings was found to be best. All rectifiers are liable to a condition commonly known as "back-fire," which means that one anode develops a cathode-spot and at the appropriate moment in the cycle an arc is formed to one or more adjacent anodes. This constitutes a short circuit on the transformer secondary winding, and gives rise to severe mechanical stresses. Furthermore, since traction is the service for which rectifiers are mostly employed, short circuits on the D.C. side are comparatively frequent. Consequently, the design of rectifier transformers demands more than the usual skill in order to ensure that they will withstand the onerous conditions of service to which they will be subjected.

A most important industrial application for which transformers are required is in relation to electric furnaces. These are of two types, (1) resistance, and (2) arc, the former being used largely for heat treatment of materials, metal, ceramic, etc., while arc-furnaces are used for the melting of metals, particularly the production of special cast iron, alloy steels, ferro-alloys and some non-ferrous metals and alloys.

Transformers required for resistance furnaces are comparatively simple power transformers, the only special feature being the arrangement of the windings with various connections and tappings in order to give alternative furnace loadings.

Transformers for arc-furnaces, on the other hand, are very special and demand careful consideration so that they may be suitable and reliable for their onerous service. The use of

arc-furnaces has increased so rapidly in recent years that it may be of interest to recount some of the reasons for their adoption.

It is not suggested that the electric arc-furnace can be justified on technical and economic grounds as compared with the usual methods using fuel fire, where the process is merely the more or less continuous melting of crude metal in large quantity, but it is a fact that for many applications the arc process is more economical than any other, and there are many very special alloys, the production of which has only been made commercially practicable by the use of the electric arc-furnace. Fundamentally, the routine use of an arc-furnace is simple as compared with a fuel-fired furnace, the period of a melt being comparatively short and the heating of a cold furnace being easily accomplished in a short time, thus resulting in financial savings. A further important economy is achieved because small quantities of alloys can be made, and the same furnace may be used for a range of different processes without much difficulty or delay. This advantage is great in its effect on minimum stocks of materials that must be carried. The reasons why the arc-furnace produces high quality materials are largely that the flexibility of the transformer supplying the power to it gives almost perfect control of the conditions of temperature; also there is no contamination of the charge by the products of combustion which is inevitable in a fuel-fired furnace; furthermore, the control of the furnace atmosphere, which in many cases is an important factor, can be achieved quite readily.

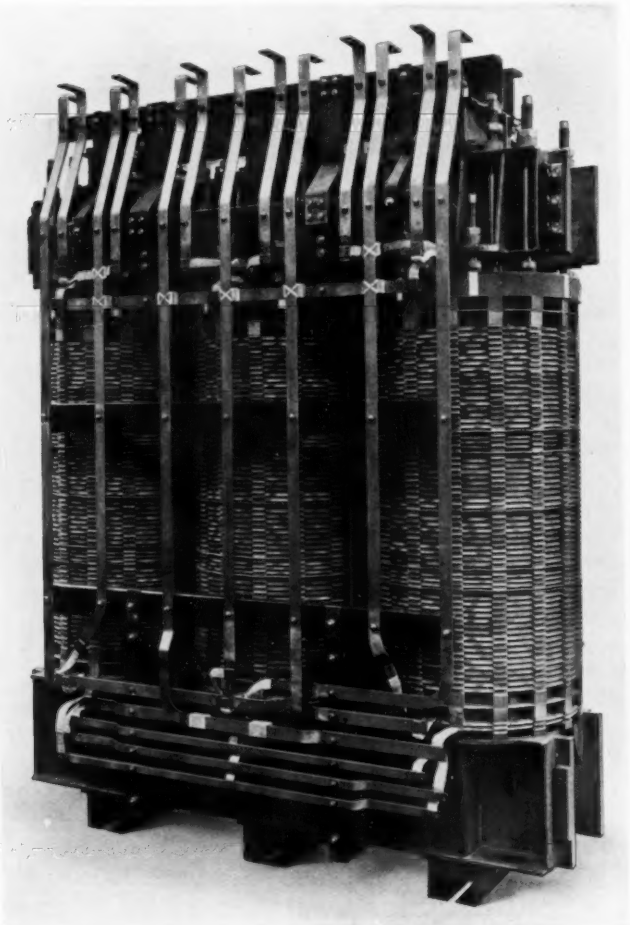


Fig. 1.—Core and windings of transformer for 2,500 kW Rectifier.

The primary feature in an arc-furnace transformer is that there must be provision for varying the voltage on the furnace electrodes over a wide range, sometimes as much as two to one or even more, but usually it is not necessary for this to be done while the transformer is carrying load or even connected to the primary supply. On account of the heavy current output of the secondary winding, the tappings for voltage variation are located on the primary winding, and the usual scheme is such that half the range is obtained with the winding star connected and the other half by changing the winding to delta connection. An

example is illustrated in Fig. 2, from which it will be seen that with all the winding in circuit and star connected, the minimum secondary pressure of 104 volts is obtained; then the pressure is increased in two steps to 133 volts, when the connection is changed to delta and the same series of tappings allows the pressure to be further increased to 230 volts. The fact that the voltage variation on the secondary side is obtained by tappings on the primary side means that the core flux density varies in the same ratio as the tapping range, apart, of course, from the further range obtained by changing the connection from star to delta. This fact involves a larger core, and therefore windings and other features are increased in size, but obviously, it is generally quite impossible to provide the voltage regulating arrangement on the secondary winding.

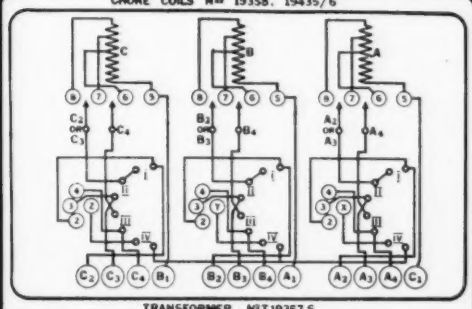
It will be recognised that in starting up a furnace containing largely metal of low resistivity there is a short circuit across the electrodes, and even with the lowest voltage tapping a very heavy current would flow. In order to control this effect within reasonable limits, it is usual to use a separate reactor in series with the primary winding, the reactor being provided with several tappings.

The complete diagram of connections for the transformer and reactor is shown in Fig. 2. The transformer primary tappings are taken to a switch mounted in the reactor tank, this switch having three positions for delta connection and one for star connection on which any one of three voltages can be used by pre-selection on a link board. There are three reactor tappings which, by means of links, can be pre-selected in combination with transformer tappings as indicated. In this example the reactor and switch are mounted apart from the main transformer, but it is more usual now to accommodate the whole equipment in one tank.

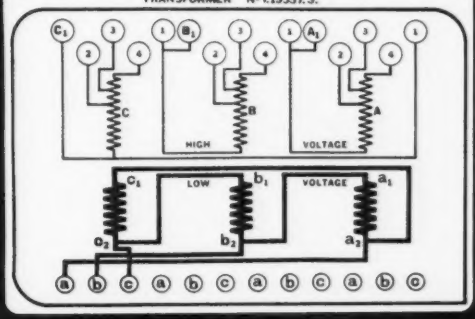
The transformer is a 6,000 kVA. unit for a 20-ton Efco-Heroult arc-furnace supplied by the Electric Furnace Company, Limited, London, illustrated in Fig. 3. There are three electrodes, the connections to which are seen at the extreme top of the picture in tubular form with the heavy

THE ENGLISH ELECTRIC COMPANY LTD
STAFFORD, ENGLAND.
O.W. TRANSFORMER & CHOKE COILS
6000 K.V.A. THREE PHASE 50 CYCLES
6000 TO 230 VOLTS (AT NO LOAD)
IMPEDANCE VOLTAGE AT 75°C [redacted] PER CENT AT ABOVE RATING
REFERENCE NO [redacted]

CHOKE COILS Nos 19358. 19435/6



TRANSFORMER No T.19357.S.



HIGH VOLTAGE				LOW VOLTAGE		
VOLTS	SWITCH POSITION	CONNECTION	ON CHOKE COILS CONNECT	VOLTS	AMPS	CONNECT LINES TO
6000	I	DELTA	—	230	15000	a b c
	II	"	—	210		
	III	"	—	180		
	IV	STAR	A_2 - X, B_2 - Y, C_2 - Z	133		
	IV	"	A_3 - X, B_3 - Y, C_3 - Z	121		
	IV	"	A_4 - X, B_4 - Y, C_4 - Z	104		

CHOKE COILS	
VOLTS AT F.L. CURRENT	ACROSS
1125	A_8 - A_9B_9 - B_8C_9 - C_8
750	A_6 - A_7B_7 - B_6C_6 - C_7
375	A_5 - A_6B_5 - B_6C_5 - C_6

TEMPERATURE RISE 50°C BY THERMOMETER.
OIL LEVEL MUST NEVER BE ALLOWED TO FALL BELOW POINT MARKED "COLD OIL LEVEL" ON GAUGE. OIL [redacted] GALLONS.
S 962 F 1262.B. WATER: 25 GALLONS PER MINUTE. 21-9-32.

Fig. 2.—Diagram of connections for 6,000 kVA Furnace Transformer.

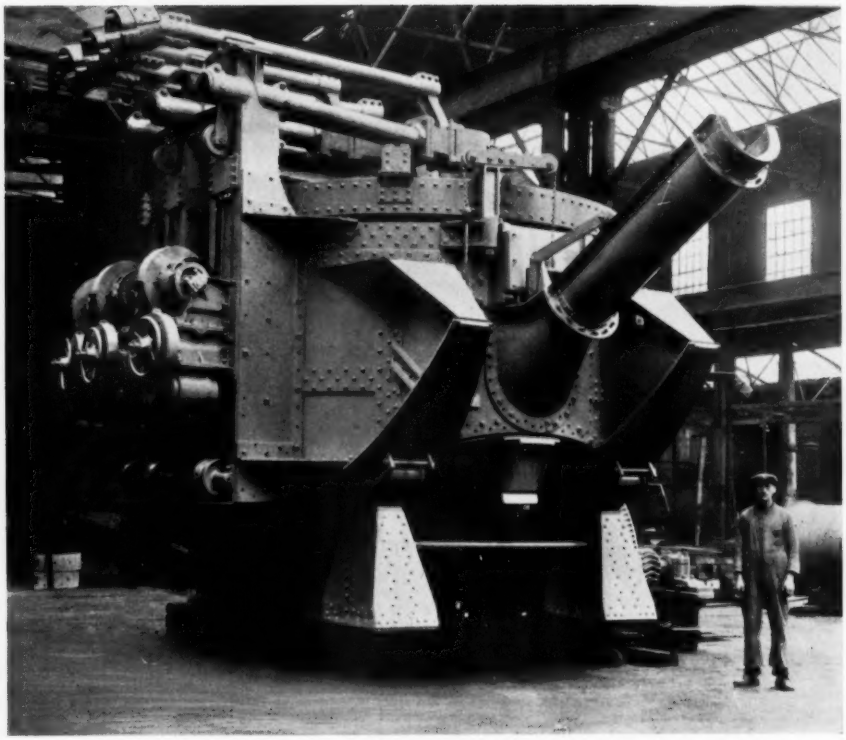


Fig. 3.—20-Ton "Efco-Heroult" Arc Furnace.

connectors at the left. Underneath these connectors will be seen the motor-operating gear for raising and lowering the electrodes, each one being separately controlled. The charge is put into the furnace through a vertical door at the back and the metal is poured through the spout at the front, the furnace being tilted by means of the rack seen under the furnace.

The transformer is shown in Figs. 4 and 5. It is of the three-phase core type. The primary or 6.0 kV. winding is nearest the core and is a five-layer spiral winding with a tapping on each of the two inner layers. The secondary winding, having to be suitable for a current of 15,000 amperes, is arranged outside the primary winding, and comprises a number of disc coils each of eight turns; in each phase these coils are connected in parallel in four groups, the conductor being welded to heavy copper bars; the bars of opposite polarity are interlaced right up to the terminals outside the tank cover in such a way as to reduce the voltage drop to the minimum and at the same time the delta connection is made. The coil bracing and clamping is designed very substantially to withstand the heavy and frequent short-circuit conditions that furnace service demands.

The transformer is cooled by means of a copper water-cooling coil located in a projection at the top of the main tank; the coil is divided into three sections in order to reduce the pressure of the water. The weight of the complete transformer, with oil, is 16 tons.

Incidentally, the method of cooling more popularly adopted to-day involves the use of an external water-cooled cooler through which the oil is forced by means of a centrifugal pump. An example of such a transformer is illustrated in

Fig. 6, and its service is interesting. It is a three-winding transformer for simultaneous service at three voltages within the limits of the capacity of the respective windings, as follows :—

2,800 kVA. at 30 kV.
1,600 kVA. ,, 15 kV.
2,400 kVA. ,, 5.2 kV.

The total loss under the worst condition is 40 kW. when 20 gallons of water per minute are required.

The furnace transformer described above, the diagram of which is shown in Fig. 2, is comparatively simple, but for a variety of processes it is found desirable to have a greater flexibility as regards voltage applied to the electrodes and the reactance in the primary circuit.

Figs. 7 and 8 illustrate a 500 kVA. three-phase transformer provided with such wide range of tappings and reactance values. By means of a link board certain voltages and reactances can be pre-selected, and then the switch allows for quick change from step to step over the pre-selected range, which is increased by changing the connection of the primary winding from delta to star, which is also achieved on the switch. In Fig. 7 the switch is visible, the cover having been removed. Fig. 8 shows the core and windings of the transformer and reactor ; the loose leads seen about the level of the top yoke of the transformer are to be coupled to the switch and those at the top of the picture are the links for pre-selection of tappings and reactances and are easily accessible through hand holes in the tank cover.

This 500 kVA. transformer is for use with a furnace supplied by Birmingham Electric Furnaces, Limited ; it has a capacity of one ton and is used for melting special grades of cast iron. Furnaces of this type are also used largely for the production of high-grade steel and various non-ferrous metals, and are made for outputs up to at least 50 tons.

Fig. 9 illustrates a typical furnace of one ton capacity. The transformer is in a compartment immediately behind the furnace ; the tapping switch is operated by a handwheel which is mounted on the switchboard. In the larger sizes the switch is motor-operated and remote-controlled.

In Fig. 10 is seen a complete furnace and transformer installation, the former supplied by Birmingham Electric Furnaces, Limited. This type of equipment is only built in comparatively small sizes and for single-phase supply. The furnace is of the rocking-arc type ; the whole

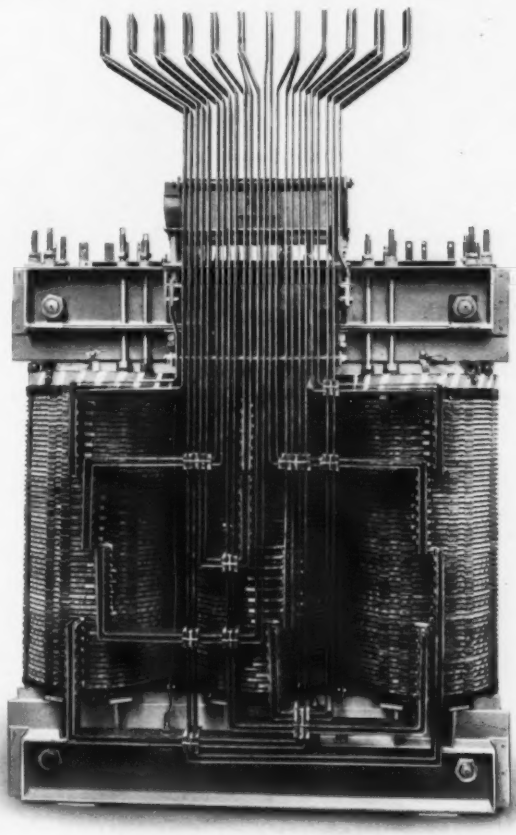


Fig. 4—Core and Windings for 6,000 k.V.A. Transformer for Arc Furnace illustrated in Fig. 3.

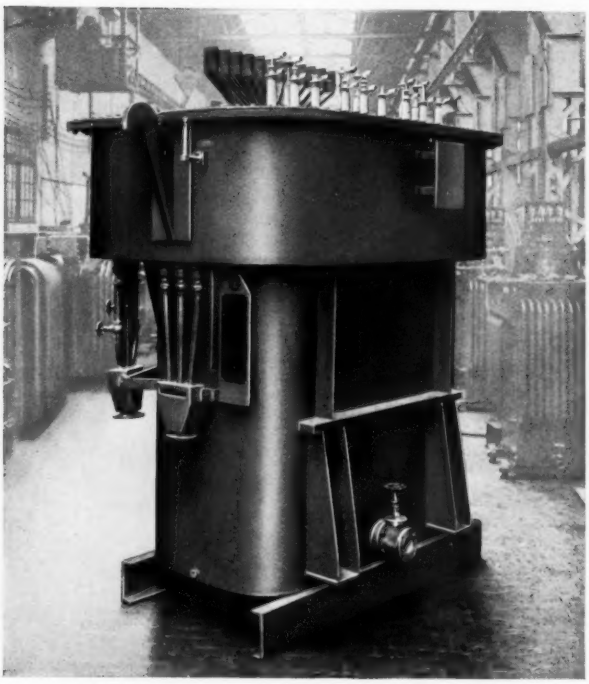


Fig. 5.—Transformer illustrated in Fig. 4, completely assembled.

furnace rocks during the melting process through an angle of 150 deg. at a frequency of about 10 per minute when the charge is fully molten. The electrodes pass through opposite ends of the furnace on the horizontal axis. This type of furnace is particularly suited to the production of alloys where uniformity of metal is of considerable importance.

The transformer has an output of 208 kVA.; tappings connected to a switch give secondary pressures of 81 to 99 volts in 7 steps, the current being 2,310 amperes.

Electric furnaces are also used for other processes, such as the manufacture of carborundum, calcium carbide and the production of nickel from the crude ore. Although there is no arc in such furnaces, the general scheme of transformer and voltage range required is similar to the examples described above, but large outputs are required and the processes are such that the load factor is extremely high.

The application of the electric current for welding purposes has been in use for a number of years, but in recent times the principle has been applied to an enormous variety of commercial purposes. Many of these use the resistance principle, either by flash or spot-welding, or by continuous resistance welding, or again by arc-welding; but in every case a transformer in some special form or other is required. For flash or spot-welding processes some very ingenious machines are in use, and the transformer is built into the machine itself. Some of such applications involve current values of some tens of thousands of amperes. A very interesting application of the continuous resistance welding process is in the manufacture of steel tube. Until a few years ago the tube used for transformer oil-cooling arrangements was nearly all seamless, the tube being usually 2 in. diameter and not less than No. 12 gauge. Such tube to-day is almost entirely electrically welded in special machines, such

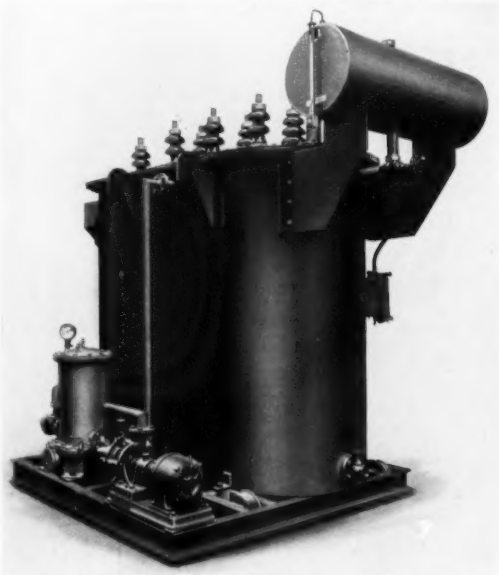


Fig. 6.—Three-Winding Transformer with forced-oil-circulation and water-cooling.

Fig. 7.—500 kVA Transformer for 1-Ton "Birlec" Arc Furnace.

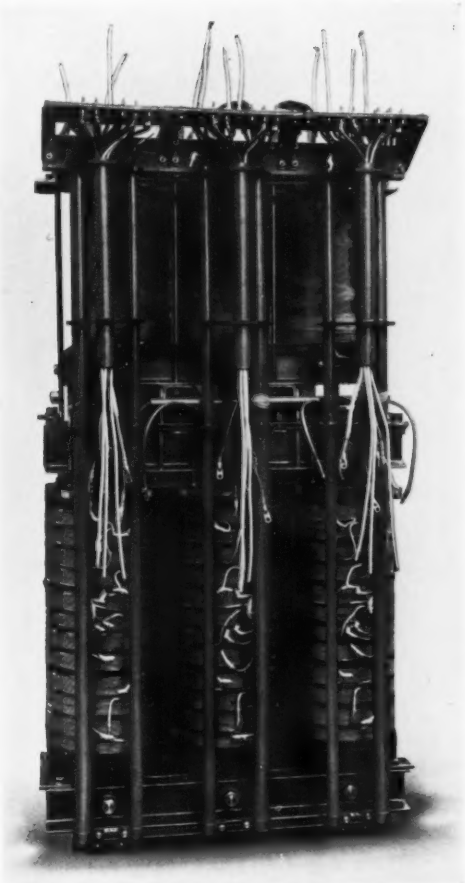


Fig. 8.—Core and Windings for Transformer illustrated in Fig. 7.

as that illustrated in Fig. 11, which is installed in the works of Tube Products, Limited, Birmingham. It was designed and developed by Mr. F. W. Martin, who is the Engineering Director of the Company. The machine incorporates a number of special patents previously operated on other machines. The process demands a high grade of steel and No. 16 gauge may be used for 2 in. diameter transformer tube. Steel strip of suitable width is folded and rolled into the circular section with the edges butting and then the tube passes between copper roller electrodes by means of which a heavy current is passed across the joint, to which, at the appropriate moment, pressure is applied, thus making a perfect welded joint. The process is continuous, the speed for 2 in. diameter No. 16 gauge tube being about 50 ft. per minute.

The transformer is a single-phase unit of the shell type; the secondary winding, which must supply a very heavy current continuously, is cast in copper in a "toast-rack" form and the primary winding coils are inserted between the grids with suitable spacing for air cooling, which is provided by means of a fan mounted above the transformer. The secondary winding is cast into two copper castings, which form the terminals for the roller electrodes, and these terminals are the

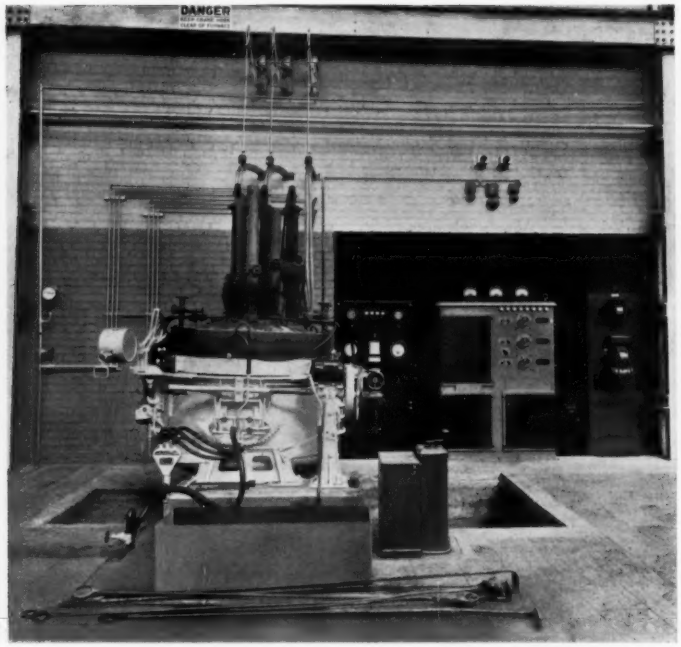


Fig. 9.—1-Ton "Birlec" Arc Furnace.

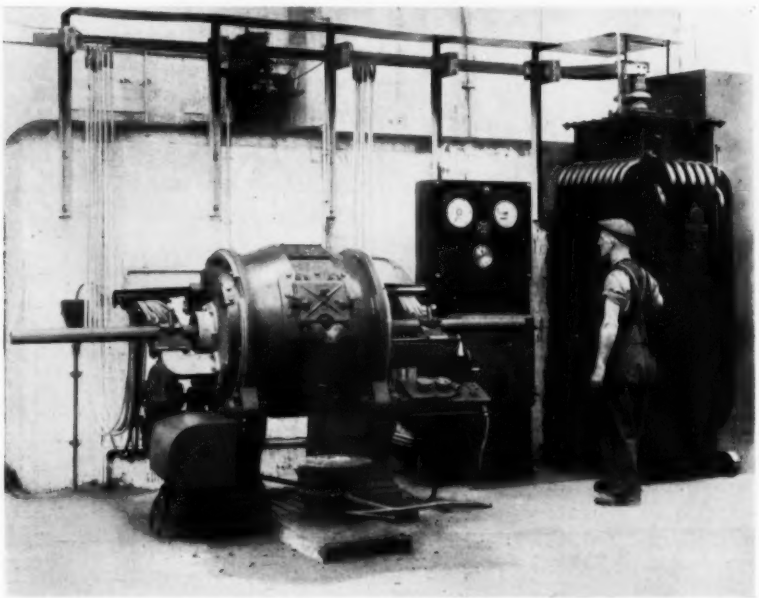


Fig. 10.—"Birlec" Rocking Arc Furnace and Transformer.

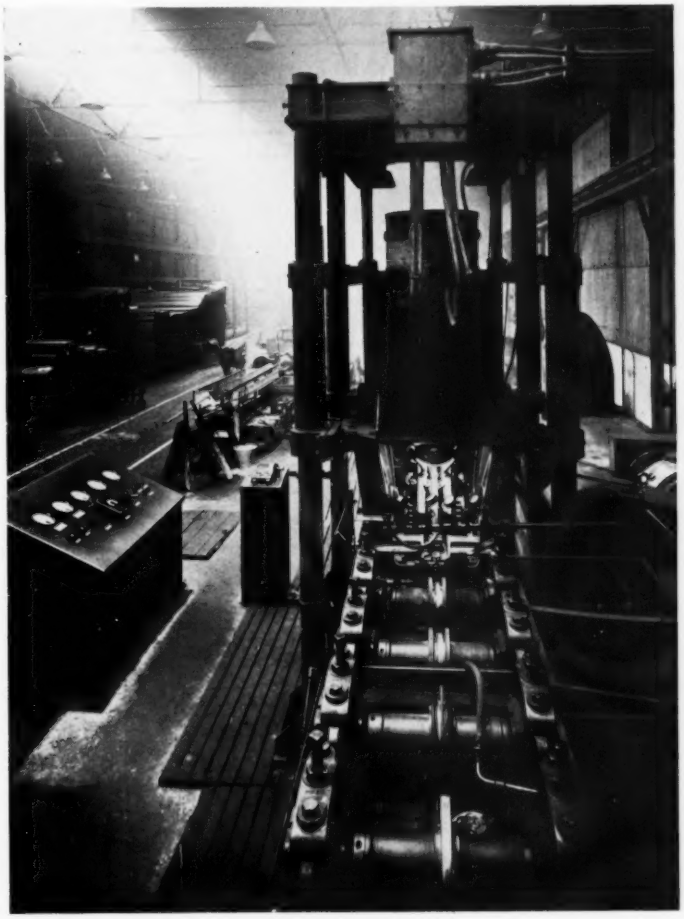


Fig. 11.—Continuous Tube Welding Machine—Tube Products Limited.

base on which the whole transformer is built. It is mounted on a suitable frame, which is supported on four vertical pillars on which its level may be adjusted to suit various diameters of tube, the movement being obtained through a motor-driven worm. A wide range of voltage can be applied to the electrodes by means of a regulating transformer which is in series with the primary winding of the welding transformer. Current control in the welding process is extremely important; the supply is obtained from a synchronous motor-driven single-phase generator on which automatic voltage control is provided. Fig. 12 shows the transformer with the housing removed, with the fan above it, and the motor-operated raising and lowering gear, with handwheel for emergency operation.

In Fig. 13 is illustrated a special transformer equipment used for rapid electric heating of joints that are to be made by a brazing process. The primary winding is controlled by a switch-fuse and in the circuit is a foot switch and contactor. The heavy current secondary winding is connected by means of convenient lengths of flexible cable to specially designed pliers having carbon electrodes. The metals to be joined are lapped; the brazing medium is inserted in the joint; the operator grips the joint between the carbon electrodes of the pliers and applies pressure; he then presses the foot switch, which causes current to flow across the joint and the brazing operation is completed in a few seconds. This device should find a wide variety of applications.

Reference was made above to arc welding; this process, using D.C., was originated many years ago, but during the past few years the almost universal adoption of the A.C. arc-welding process has been largely responsible for the enormous increase in welding of structures for buildings, ships, electrical and other machinery, and many other applications. The A.C. process requires a special transformer and current regulator, which are comparatively cheap and efficient and require little maintenance.

A multi-operator equipment comprises a three-phase transformer specially designed to give ideal

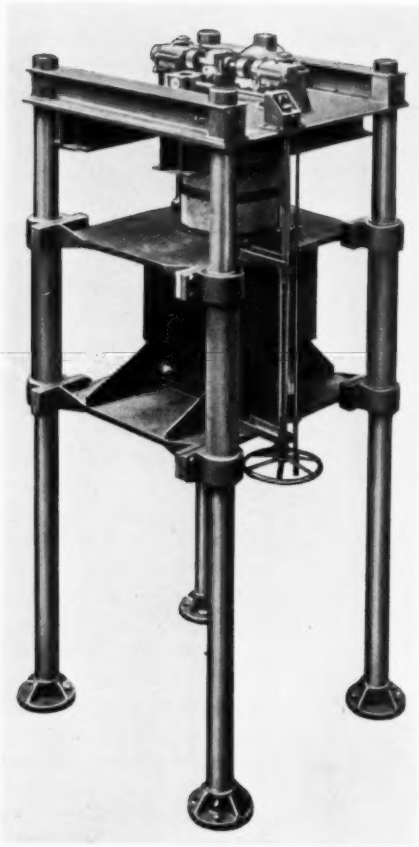


Fig. 12.—Transformer for Machine illustrated in Fig. 11.

welding characteristics and to avoid interference between the various welding circuits, even if one operator may be welding at a very low current and another at the maximum current; provision is made on the secondary side for three, six, twelve, or even twenty-four operators. In each welding circuit is a separate regulator which comprises a tapped choke coil with a special winding arrangement that gives thirty-six current values with only twelve tappings. Such current regulators have been supplied in large numbers for maximum currents of 200 amperes, 300 amperes, 400 amperes and recently 600-ampere equipments have been built. The latest aircraft-carrier "Ark Royal," the largest ship of its type afloat, built by Messrs. Cammell Laird & Co., Ltd., Birkenhead, had most of its interior construction welded by such A.C. equipments.

Portable equipments are built with a single-phase transformer and regulator in a single tank arranged for convenient transport around a shop or yard. Fig. 14 shows a group of four 600-ampere portable equipments which are probably the largest of this type yet built.

Recently an entirely new transformer equipment has been developed for use with a special automatic welding process requiring large current, used for applications such as the welding of longitudinal seams of boiler drums. Fig. 15 illustrates an equipment suitable for a welding current of 1,000 amperes. Two or more such equipments can be automatically operated in parallel to give sufficient current so that steel plate even as thick as 3½ inches may be welded with a single run.

A single-phase transformer and choke coil connected in series with its secondary winding are assembled on the same core structure, but the magnetic circuit for the choke coil is completed through a variable air gap made by means of a movable core. This core is operated by a small motor through a reduction gear and worm shaft rotating in a nut in the core, and the motor is controlled by "raise" and "lower" switches. Since the current in the welding circuit is determined entirely by the position of the movable core, this current can be accurately indicated on a dial; a big advantage of the design is that the current may be varied without interrupting the welding operation.

An application of transformers that is valuable from the point of view of safety to human life is the provision of a low-voltage supply for "safety lighting." There are numerous applications where the available pressure for the lighting circuit, which may possibly be between 110 volts and 520 volts, would constitute a real hazard to the life of the operator. This is true in every case where a hand lamp with a length of flexible cable is used. Another typical example is the individual lighting of machine tools, where the lamp is usually mounted on a multi-jointed bracket. These and many other applications are demanding

Fig. 13.—Application of a Transformer in a brazing process.

low-voltage "safety lighting" at 50 volts or 25 volts and even 12 volts, and such service requires suitable transformers.

Fig. 16 shows a typical wall-mounted transformer arranged for conduit connections, but, if desired, two sockets and plugs can be fitted for the connection of two flexible leads for hand lamps. Fig. 17 shows a portable transformer fitted with two plugs. In the former type the primary supply is taken into the case through conduit entry, but for the portable type the supply lead is a length of heavily insulated rubber 3-core cable, permanently attached at one end to the transformer and at the other end a three-pin plug would be fitted. In each pole of the supply is a fuse of the Bulgin glass type, and in each circuit of the low-voltage lighting supply is a fuse of the Kantark rewirable type. Between the H.V. and L.V. windings is a copper earth shield, which is connected to the transformer core and to an earthing terminal. In the portable type this terminal is connected to the earth core of the 3-core supply cable, and an earth testing plate is provided, contact with which is gained by inserting a prong through a hole in the wooden box. Thus every precaution is taken to safeguard the operator and the transformer.

The wall-mounted type transformer is contained in a substantial steel case in which the cover and socket fittings are dust-proof. The portable type transformer is built into a wooden box of heavy construction provided with a carrying handle. In both types the transformer core and windings are covered with a suitable insulating compound.

Transformers as described above are used in large numbers for the various factories of Imperial Chemical Industries, Limited. They are not cheap, but it must be remembered that the whole object of the low-voltage lighting scheme is the protection of human life, and hence the extra cost of providing the additional features which give greater reliability and safety are well justified.

A similar application is for oil fields or oil refineries where the supply transformer must be flame proof and capable of withstanding the "Pentane" test of H.M. Mines Department.

Although not strictly a transformer according to the generally accepted definition, an interconnected star balancer and an earthing trans-

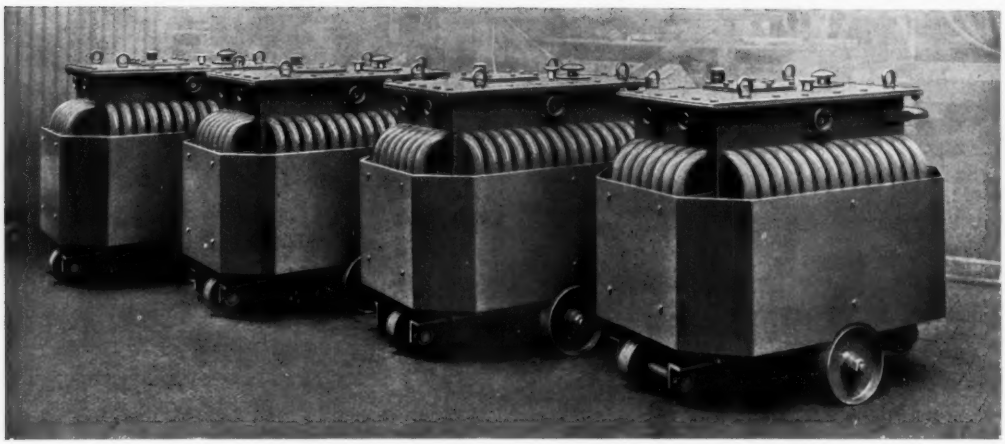


Fig. 14.—600-Ampere Portable Arc Welding Equipments.

Fig. 15.—1,000-Ampere Transformer Equipment for special automatic welding process.

former are interesting examples of the application of equipment of the transformer type. The majority of low-voltage distribution is three-phase 4-wire, in which a large proportion of the load is single-phase connected from line to neutral. Under these conditions it is inevitable that at times there may be a considerable amount of out-of-balance in the loading of the three phases, which gives rise to an out-of-balance current in the neutral or fourth wire. Such a condition produces unsymmetrical voltages on the three phases, which may be equally unsatisfactory in that the pressure may be considerably above normal on one phase and below normal on another phase. The application of an interconnected-star balancer is a most effective and economic means of largely overcoming these adverse conditions. It comprises a three-limb core of usual construction with a simple three-

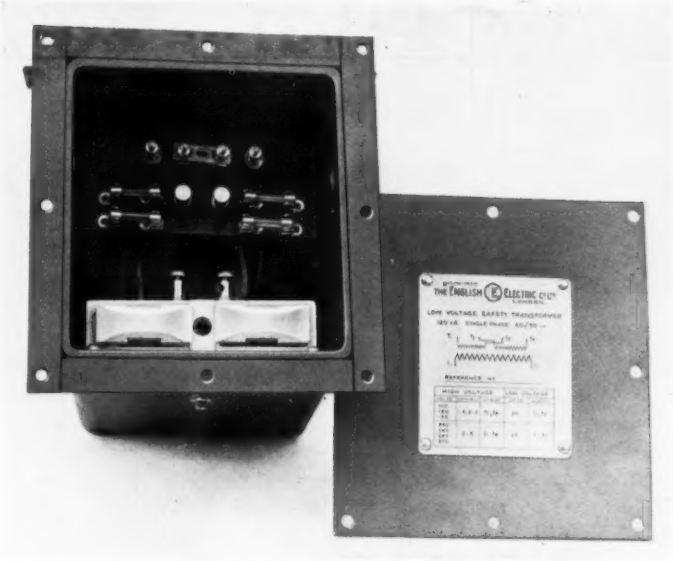


Fig. 16.—"Safety-lighting" Transformer—Wall mounted type.

phase winding arranged in the interconnected star manner, the phase ends being connected to the lines and the star-point to the neutral or fourth wire. These balancers should be located in the distribution system at points carefully chosen, depending on the distribution of the load. The reason for the interconnected star arrangement is that it is essential for the impedances of the three phases to the out-of-balance current to be such that this current will split up equally into the three lines. In some cases, in order to ensure that most of the out-of-balance current will flow through the balancer rather than continue back along the fourth wire, a choke coil is inserted in the fourth wire immediately behind the balancer between it and the supply point. This arrangement is very effective even up to an out-of-balance current equal to the full-load current of the system, and there is every justification for its very wide adoption on three-phase 4-wire distribution systems.

It sometimes happens that certain transformer connections have to be employed, resulting in the absence of any neutral point which may be used for earthing the system. In such cases an earthing transformer, which is designed on similar lines to an interconnected-star balancer, is employed, but only one unit is necessary on a system, and it would probably be located at the main substation. The necessity for the interconnected star winding is similar to that applying to the balancers described above, but in this case the really important factor is that under all conditions of loading the neutral point, as provided by the earthing transformer, shall be as close as possible to the true neutral of the system. Sometimes the neutral is connected to earth through a resistance or impedance, but more usually it is

Fig. 17.—"Safety-lighting" Transformer—Portable type.

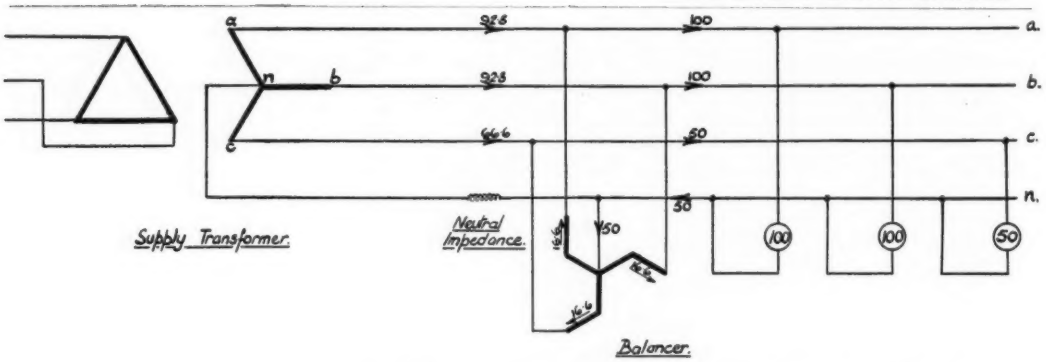


Fig. 18.—Application of interconnected-star Balancer to 3-phase, 4-wire distributor—diagram showing current distribution with unbalanced loading.

so designed, by suitable arrangement of the windings, that it is capable inherently of limiting the earth fault current to a pre-determined value, which may be the full-load current of the system. It is assumed, of course, that an earth fault will be cleared by the usual protective equipment in a reasonably short time, say 5 seconds, but, nevertheless, rather than risk damaging the earthing transformer and since the extra cost is not great, it is very desirable to build it for a longer time rating, which should not be less than 30 seconds.

As previously stated interconnected-star balancers and earthing transformers are not transformers in the usual acceptation of the term and they may be considered as being akin somewhat to reactors, which, although unproductive of useful power for supply purposes, are very necessary for the protection of systems. An article describing the latest application of such reactors to the English 132 kV. Grid appeared in the March, 1937 (Volume VIII, No. 5) issue of the English Electric Journal.

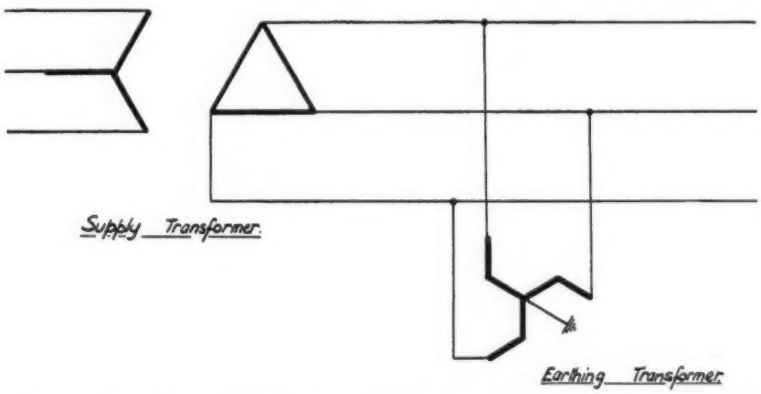


Fig. 19.—Application of interconnected-star Earthing Transformer to provide a neutral point on a delta-connected system.

Electric Fuses.

Some Observations on B.S.S. 88/1937 and the Factors Governing the Choice of the Type of High-rupturing Capacity Fuse to be used.

By A. M. POOLEY, M.B.E., Manager, Fusegear Section.

(Concluded from page 14, Vol. IX, No. 1.)

In the last issue of this Journal, Vol. IX, No. 1, March/April, 1938, reference was made to the non-deteriorating properties of the Company's fuse even when operated for long periods under overload conditions. This statement is substantiated by fuses operating under laboratory conditions and by the condition of the fuses returned to the Company unblown, after being operated under exceptionally heavy service conditions for several years. A typical laboratory test consisted of running a 300-amp. fuse at 375 amps. for 1,008 hours. The resistance of the fuse was measured before and after the test, the difference at the conclusion being 0.1 per cent.

A customer recently returned to the Company for examination and report six 200-amp. fuses taken from rectifier circuits, which had been in continuous heavy traction service with considerable overloads at peak periods for six years. The fuses were unblown, and when the resistance was compared with the Company's standard of the appropriate rating, they were considerably within the tolerances for new fuses. On opening up the cartridges the silver element was found to be correct to size and as bright and clean as when first assembled. The cement seals and body were perfect, while the filling was perfectly dry and sound.

The discrimination value between two fuses of different ratings is interdependent on the current value of the short circuit. The higher the short-circuit current value the greater the margin required between the ratings, and conversely, the lower the current, the closer will be the discrimination obtained.

Some examples of the results obtained on a very wide range of tests are given below :—

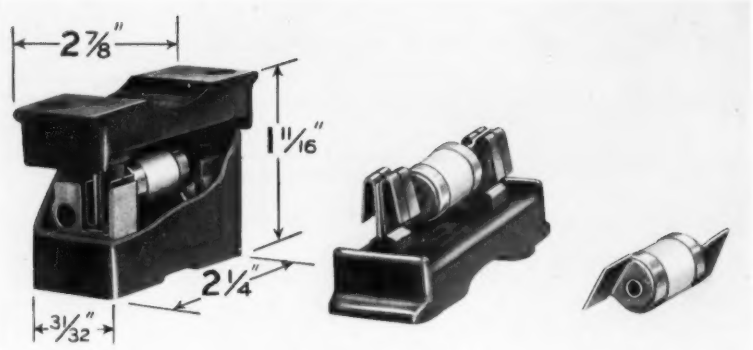
Fuse used: J-type (link disconnecting box).

Test circuit: 260 volts, D.C., prospective current 33,000 amps.

The 100-amp. fuse showed discrimination with the 200-amp. fuse, whereas with a 125-amp. fuse in place of the 100-amp., discrimination was not obtained. When the prospective current was reduced to 3,000 amps., it was found that discrimination was obtained between the 160-amp. and the 200-amp. fuse.

When a fuse has discriminated against one of larger rating, the question at once arises as to whether the fuse of larger rating has been affected. In order to establish definite information the foregoing tests between the 100-amp. and 200-amp. fuses at 260 volts with a prospective current of 33,000 amps. was repeated six times at short intervals, and in every test the 200-amp. fuse remained intact. The identical 200-amp. fuse was used in each of the six tests, and a detailed examination at the conclusion revealed that the fuse was perfectly normal and that no deterioration had taken place. That the larger fuse remains healthy is a very good characteristic, as it saves the cost of replacing the larger fuse as well as the smaller one.

In another series of tests, using the Company's standard T-type fuse, which were carried out at 440 volts with a prospective current of 16,500 amps. and a power factor of 0.2 lagging, discrimination was obtained between fuses of 100 amps. and 200 amps., 160 amps. and 300 amps.,



The new type S.S., 25 ampere, 250 volt, B.S.S. category A.C.3 and D.C.3 Fuse and Fitting.

200 amps. and 400 amps., and so on up to 800 amps., with a current rating difference of 200 amps only.

Continued expansion in the use of 2,000-volt and 3,000-volt single-phase distribution in suburban districts and the adoption of the " English Electric " high-tension fuse as the most economical means of preventing transformer faults being reflected further back on the network, made necessary a determination of the discrimination value between the Company's low-tension fuses and high-tension fuses used in the circuit. Site tests were carried out, and it was determined that when the transformer was protected by a 50-amp. fuse, type P.50, and a low-tension fuse of 160 amps., satisfactory discrimination was obtained. When a 100-amp. fuse was used on the high-tension side, a 300-amp. fuse provided satisfactory discrimination. In both cases the low-tension fuse operated and the high-tension fuse remained unaffected.

The increase in the size of substations makes it necessary for the supply undertaking to install a high-rupturing capacity fuse possessing quick-acting features at the consumer's intake. For a medium installation a current rating of 60 amps. is used. That high speed of rupture is inseparable from high-rupturing capacity makes a complication when consumer's main fuse is of the copper wire type. It is therefore necessary to consider the time/current characteristics of the two types which are of a very different order. A series of tests have proved conclusively that the maximum sizes of copper wire fuse that can be used in series with the " English Electric " R-type service fuse, which is now available up to 80 amps., are as follows :—

An R.80.A fuse with 23 s.w.g., 20 amps. rating approximately.

An R.60.A fuse with 25 s.w.g., 15 amps. rating approximately.

These results show that the high-speed service fuse must have a rating of at least four times that of the copper wire fuse.

That the difference in ratings could be avoided by using a high-rupturing capacity fuse with high-speed characteristics in place of the copper wire fuse was proved by further tests under the same circuit conditions when a 250-volt experimental fuse rated at 25 amps. and 30 amps. was short-circuited in series with a 30-amp. and 40-amp. R-type fuse respectively. In both cases the small fuse cleared the circuit, leaving the larger fuse perfectly healthy. Further short-circuit tests on the experimental fuse proved that it complied with all the requirements of B.S.S. 88/1937, category 250 volts, A.C.3 and D.C.3. The Company decided to include this type, now known as the type " S.S." fuse, in their range of standard fuse products. The cost is only half that of an R-type fuse, and a suitable range of plastic moulded handles and fuses is available ; the cartridge fuses have tag ends, which are inserted in the spring contact-clips carried by the handle. No tool is required for cartridge replacement. The same fitting will shortly be available in 250-volt double-pole, and single-pole and neutral metalclad distribution boards and switch distribution boards. It is anticipated that this product will meet a very wide demand for important domestic and public installations.

Mica, Leatheroid, Vulcanised Fibre
Empire Cloth & Tape
Bakelite Sheets, Tubes, Spools, etc.
for Oil-immersed Apparatus & Transformers.
Ebonite
& all Insulating Material for Electrical Manufacturers

Contractors to the British, American, French & Italian War Offices & Admiralties.

Attwater & Sons, Preston, England

Established 1868

MIDLAND STEEL Co. LTD.,

— REGISTERED OFFICE —

WEDNESFIELD, Nr. WOLVERHAMPTON

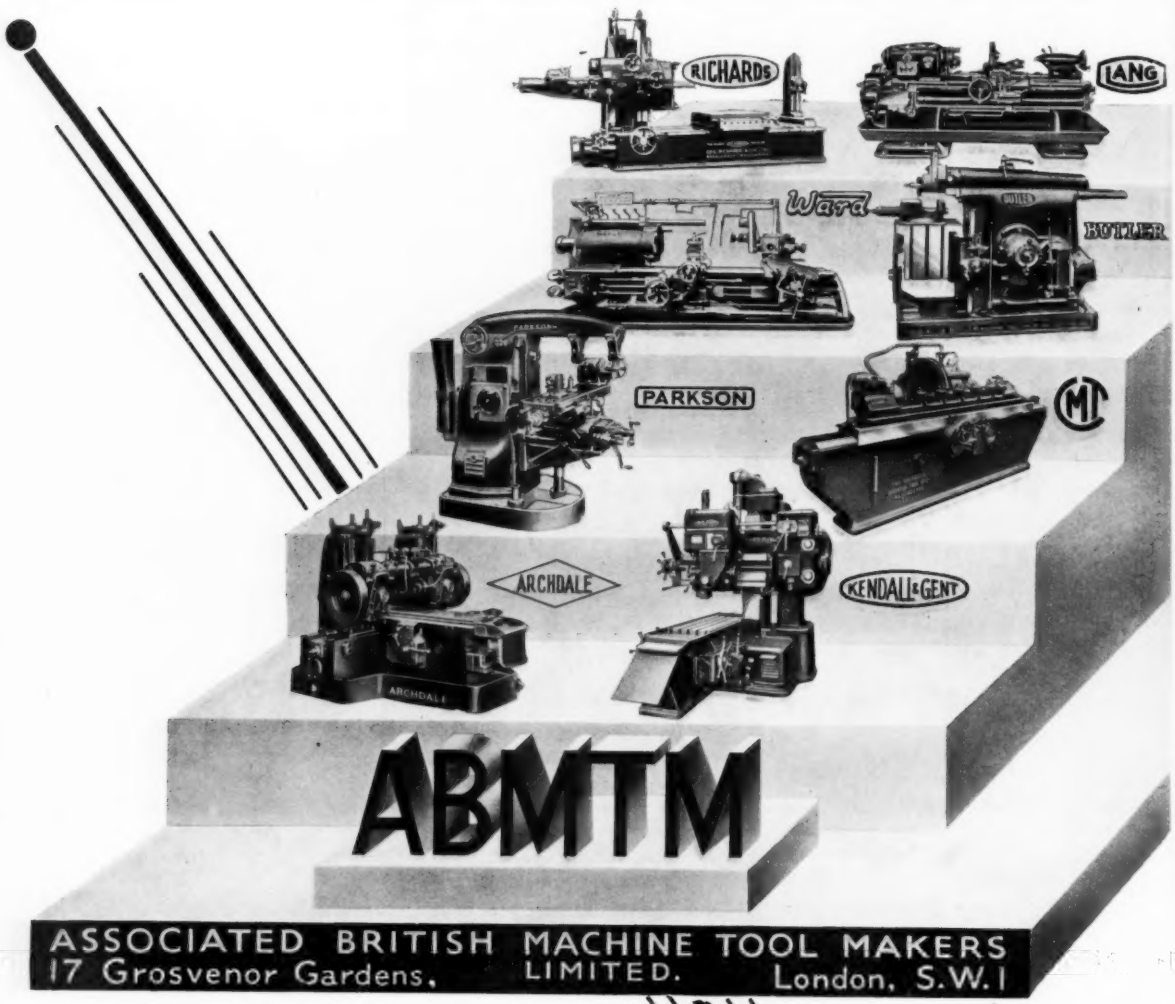
Manufacturers of

BLACK SHEETS, CLOSE ANNEALED SHEETS, CR. & CA. SHEETS, PATENT FLATTENED SHEETS, PLATES, $\frac{1}{4}$" THICK & UNDER, CIRCLES, Etc. ALSO SPECIAL DEEP STAMPING & WELDING QUALITY.

— WORKS —

WEDNESFIELD STEEL CO.,
WEDNESFIELD, Nr. WOLVERHAMPTON.
Phone: FALLINGS PARK 31375.

MIDLAND SHEET CO.,
BRICKHOUSE WORKS, WEST BROMWICH.
Phone: TIPTON 1530.



The ABMTM group of machine-tool makers covers the whole field of machine-tool building, giving the engineer at home and abroad a unique manufacturing and sales service.

Apart from the main specialities of the Associated firms, customers have the advantages of the pooled research, the accumulated experience and the entire technical resources of the whole group.

The abundant advantages thus provided by group co-operation will be obvious. The after-sales service provided is of a kind beyond the scope of the single manufacturer.

For further particulars write to:

17, GROSVENOR GARDENS

LONDON — S.W.1

BRITISH MACHINE TOOL MAKERS ASSOCS. LIMTD. TRADE MARK

SPECIFY SILVERTOWN INSULATING AND LUBRICATING OILS

"English Electric" 11,000-volt, 750,000 kV.A. rupturing capacity main metalclad switchgear at the Tongland Power Station of the Galloway Water Power Company, containing Silvertown "Penetrol" Heavy Insulating Oil.

GUARANTEED DIELECTRIC STRENGTH.

LOW POWER FACTOR.

HIGH VISCOSITY.

FLUID AT LOW TEMPERATURES.

BULK DELIVERY.

MANUFACTURERS AND PROPRIETORS OF "PENETROL" (REGD.) HEAVY INSULATING OILS AND COMPOUNDS.

TRANSFORMER AND SWITCH OILS (to B.S.S. 148/1933).
"PENETROL" HEAVY INSULATING OILS AND COMPOUNDS.
"PENETROL" CABLE IMPREGNATING OILS AND COMPOUNDS.
"PENETROL" JOINT BOX COMPOUNDS.
HOLLOW-CORE CABLE OIL (for 132 kV. and 66 kV.).
TURBINE OILS.
LUBRICATING OILS AND GREASES (for Plant, Machinery and Transport of every description).

Silvertown Lubricants LTD.

MINOCO WHARF,
WEST SILVERTOWN, LONDON, E.16.

CONTRACTORS TO THE ENGLISH ELECTRIC CO., LTD., AND PRINCIPAL GOVERNMENT DEPARTMENTS, RAILWAYS, MUNICIPAL AUTHORITIES AND INDUSTRIAL FIRMS

SUPERIORITY

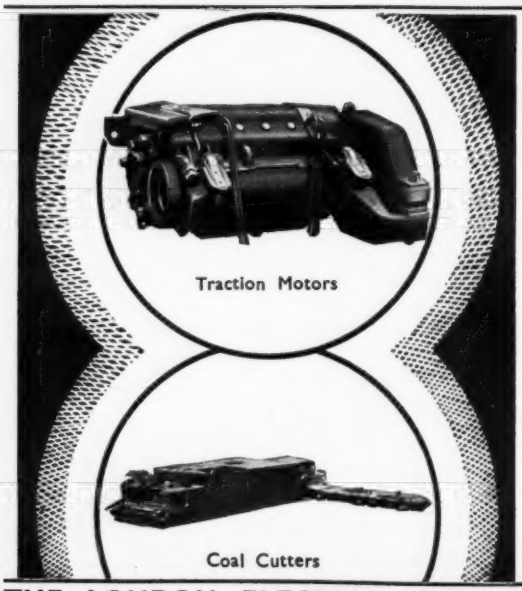
comes from infinite technical care —and experience

TAYLOR TUNNICLIFF PORCELAIN

Taylor Tunnicliff & Co. Ltd., 110 Cannon St., London, E.C.4, Factories at Hanley, Stone & Longton, Staffs. Tel.: Mansion House 7211-2 & Stoke-on-Trent 5272-4

TAS/Tt.2

TYPICAL APPLICATIONS



Lewbestos REGD.

(Pure Asbestos Fibre)

INSULATED WIRES

•

COILS WOUND WITH
"LEWBESTOS"
CONDUCTORS
DO NOT BURN OUT
WHEN SUBJECTED TO
HIGH TEMPERATURES

•

Our booklet on Modern Armature Winding gives practical and technical information. SEND FOR IT NOW!

THE LONDON ELECTRIC WIRE COMPANY AND SMITHS, LIMITED

'phone: Leytonstone 3636 (10 lines). CHURCH ROAD, LEYTON, LONDON, E.10. *'grams: "Lewcos, London."*

ELECTRICAL INSULATION

British Made to Comply with B.S.I. Specifications.

PANILAX
(Reg'd Trade Mark)
The most recent development of Synthetic Resin Insulation, either in sheets or mouldings, easily machined and specially suitable for high-frequency low-loss applications.
Write for Pamphlet PX-1/35

Examples of Fabrication

EMPIRE
Varnished insulating cloth and silk tapes.
Varnished sleeving in all colours.
Write for Pamphlet E-1/35

MICA
Cut or machined to any size or shape.
Write for Pamphlet M-1/37

MICANITE
In every form required by the Electrical Industry.
Write for Pamphlet MT-1/35

PAXOLIN
(Reg'd Trade Mark)
Varnish-paper insulation in boards, tubes, bushings & cylinders.
Write for Pamphlet PN-1/35

THE MICANITE & INSULATORS COMPANY LIMITED

Electrical Insulation Engineers & Manufacturers.

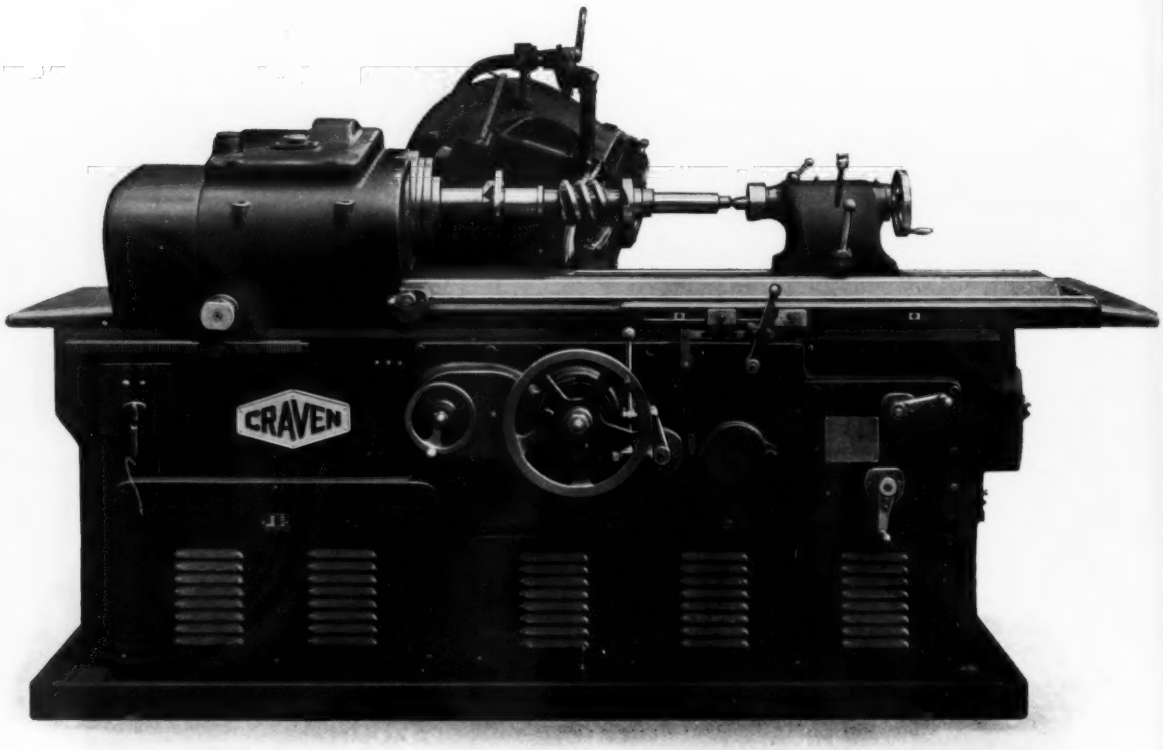
EMPIRE WORKS WALTHAMSTOW MIC

WALTHAMSTOW
LONDON. E.17.

CRAVEN

WORM THREAD GRINDING MACHINE

10 inch by 18 inch



- HIGH OUTPUT
- MAXIMUM EFFICIENCY
- CONTROL GEAR BUILT INTO MACHINE
- COMPACT DESIGN

CRAVEN BROTHERS (MANCHESTER) LIMITED

REDDISH - STOCKPORT

INDEX TO ADVERTISERS

Asquith, William, Ltd.	VI
Associated British Machine Tool Makers, Ltd.	X
Associated Equipment Co., Ltd.	—
Attwater & Sons	IX
Babcock & Wilcox, Ltd.	I
Bolton, Thomas & Sons Ltd.	IV
Broadbent, Thos. & Sons, Ltd.	VII
Craven Brothers (Manchester), Ltd.	XIV
English Electric Company Limited	IV
Germ Lubricants Ltd.	III
Ioco Rubber & Waterproofing Co., Ltd.	II
London Electric Wire Co. & Smiths Ltd.	XII
Marelli & Co. Ltd.	—
Mason, E. N., & Sons, Ltd.....	II
Micanite & Insulators Co., Ltd.	XIII
Midland Steel Co., Ltd.	IX
Siemens Brothers & Co., Ltd.	VIII
Silvertown Lubricants Ltd.	XI
Sterling Varnish Co., Ltd.	V
Straker Brothers Ltd.	XVI
Taylor Tunnicliff & Co., Ltd.	XII
Walker, James & Co., Ltd.....	V
Westinghouse Brake & Signal Co., Ltd.	XV

All communications respecting Editorial Contents and Advertising Rates should be addressed to The Editor, The English Electric Journal, The English Electric Company Limited, Stafford.

When communicating with Advertisers please mention English Electric Journal.

SWITCH-TRIPPING BATTERY CHARGERS

The Westinghouse S.R.T. rectifier has been developed for trickle-charging tripping batteries. It is completely self-contained, including main switch controlling both A.C. and D.C., two fuses, a milliameter, and resistance control for use with the transformer tapping switch to give either a trickle rate or slow charge. Normal output 38/42 volts at 10/200mA.

Westinghouse

METAL RECTIFIERS

Write for a booklet D.P.11/E.E.J.

WESTINGHOUSE BRAKE & SIGNAL CO. LTD.

82, York Way, King's Cross, London, N.1.

STRAKER BROTHERS LIMITED

THE BISHOPSGATE PRESS

Established 1800.

Printers by all Processes

194-200, BISHOPSGATE, LONDON, E.C.2

Telephone: BISHOPSGATE 2444 (4 lines)

We invite your enquiries for all classes of Printing and Stationery, and will submit, on request, Specimens and Lay-outs

for

ILLUSTRATED PRICE LISTS, WEEKLY, MONTHLY & QUARTERLY JOURNALS AND GENERAL ADVERTISING

Our Service is the result of 138 years' experience as printers.